Investigation into parameters affecting colour variations in letterset can decoration.

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Investigation into Parameters Affecting Colour Variations in Letterset Can Decoration

By

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Dissertation submitted in candidature for the degree of Master of Philosophy in the Department of Mechanical Engineering.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

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This dissertation is being submitted in fulfilment of the requirements for the degree of MPhil.

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Summary

The work carried out for this thesis was completed during a two year Teaching Company Scheme between the University of Wales, Swansea and Envases (UK) Ltd.

The Can decoration process employed by Envases utilises the letterset printing process. Although this process has been used for many years for this purpose, little to no work has been carried out to understand the effect many of the inherent process parameters have on colour variation. Due to the production constraints, a pragmatic approach was adopted to explore the effect of these parameters.

Several stages were employed during this investigation. The first of these was to highlight the current process performance, where it was found that spherical spectrophotometry must be used to measure the colour variation during normal production, due to the reflective nature of some can decoration. From this, suitable colour tolerances could be identified. This showed that the current production was of a high standard and it also highlighted the fact that a colour tolerance, ΔE of 2.5 was achievable.

The second stage was to identify if any one parameter assessed during normal production could cause a breach of the tolerance set. Also investigated during this time were many of the procedural systems. This highlighted that no single variation in a process parameter, during normal production, is large enough to cause colour variation in excess of suggested tolerances. However, the need for standardisation of many process procedures was highlighted and strategies for achieving this were identified.

The final stage of the work was to standardise the process. This involved standardising the ink film thickness to further reduce colour variation. It was shown that an ink film weight corresponding to a deposit of $1.5 g/m^2$ minimised colour variation whilst keeping within acceptable production requirements. The development of a colour formulation system was also explored and established successfully. This led to the achievement of a ΔE of 2 or less with respect to the target colour after no more than 2 attempts (many matches were achieved on a first time basis). This compares favourably with colour matching by empirical means, often requiring up to 8 attempts to reach a satisfactory match. The work represents one of the first successful applications of colour matching in can decoration

CONTENTS

List of Figures

CHAPTER 1
INTRODUCTION

1.1 Introduction

This thesis has been compiled using the work carried out over a two-year Teaching Company Scheme project between the University of Wales Swansea and Envases (UK) Ltd. The project was primarily concerned with the investigation and subsequent improvement of the offset printing process employed at Envases in the decoration of monobloc reverse extruded aluminium aerosol cans. This was achieved by adopting a pragmatic approach allowing production to continue uninterrupted. This approach also allowed the results to be of greater relevance to the company, an aim of the Teaching Company Scheme programme. However this thesis highlights the research aspects that were addressed during the course of this work programme. The Company has already benefited considerably through the findings of this project, many of which are being implemented successfully into their manufacturing processes and procedures.

1.2 Industrial partnership

The work contained in this thesis was all carried out on site at Envases (UK) Ltd. Envases are a market leader in the production of monobloc extruded aluminium aerosol cans. They are a Spanish company with their base in Bilbao in Northern Spain. A new production site at Baglan, South Wales was opened in 1994 and now has four production lines, producing approximately 60 million pieces a year and employs in excess of 150 people.

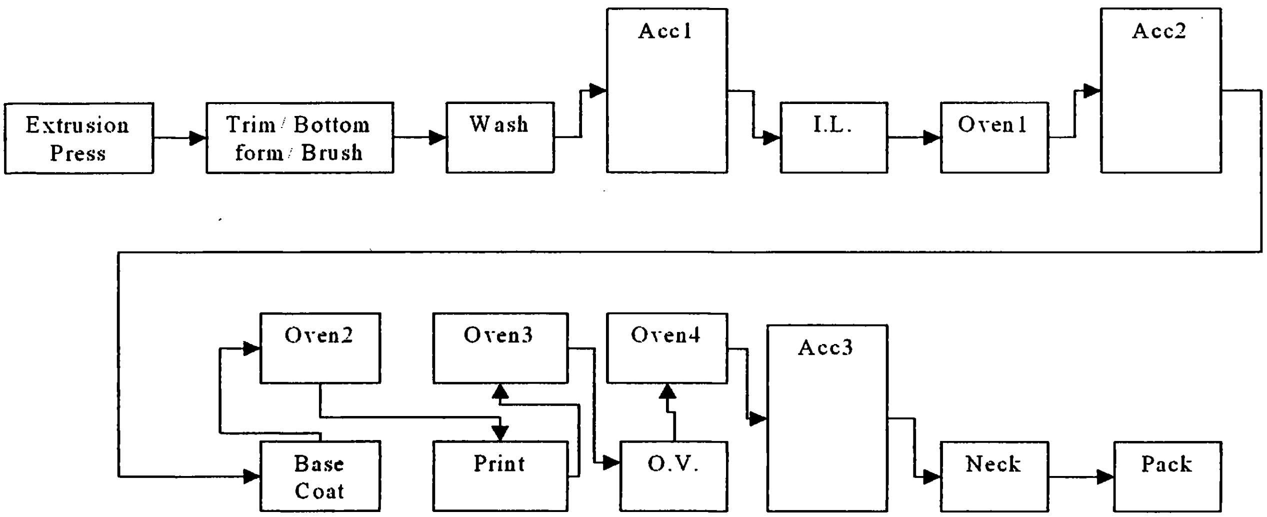
The production process begins with the extrusion of an aluminium disk shaped slug, which finishes as a fully formed and printed can. The production lines allow this to be a continuous and uninterrupted process. The manufacturing process will be described in detail later in this chapter.

The cans produced are available in a variety of diameters, heights and shapes to meet customer requirements as shown in Figure 1.1. Once the cans have been produced they are then transported to the customer, where they are filled and marketed.

Figure 1.1 Assorted Aerosol Cans

1.3 The Manufacturing Process

The manufacturing process is split into the four distinct sections, as displayed in Figure 1.2. The process is completely automated, with minimum human interaction. Between each section, there are accumulators, which allow a section to remain idle for a period of time with out affecting the other sections of the line, thus almost allowing uninterrupted manufacture. Each section of the process will be discussed in further detail below.



I.L. - Inside Lining

O.V. - Over vanish

ACC - Accumulator

Figure 1.2 Can Formation Process

1.3.1 Extrusion

Extrusion is the first section on the line and involves the formation of the can. This is achieved by the backward extrusion of aluminium slugs, which vary between 35-66mm diameter and 6.8-7.6mm thickness depending on the size of can required.

The aluminium slugs, which are coated in a lubricant to aid extrusion, are placed into the base of a die and the extrusion punch is driven into the die, forcing the aluminium out and hence forming a can. The can is then trimmed to the correct height, depending on customer requirements. Once the can has been formed, the surface is then brushed in order to obtain a textured surface, which is not only more aesthetically pleasing, but also produces an even surface on which further processes can be performed. The can is then washed to remove any excess lubricant, dirt or aluminium, before being sent onto the inside lining section.

Can formation through reverse extrusion has been studied extensively in a previous TCS project [1].

1.3.2 Inside Lining

Once the can has been washed and dried, the inside of the can is then coated in order to apply a protective layer. This coating not only protects the future contents of the can, but also the can from the contents. The lining is applied in several coats by spraying the inside several times, ensuring a complete coverage. From this section the can is transported via a conveyor system to the Printing section of the line.

1.3.3 Printing Section

The printing press used at Envases is similar to that of a dry offset or letterset process. Described below is a brief description of the development of letterset, a more detailed account of the specific process will be described later in this Chapter.

1.3.3.1 History

As the name implies, letterset is a combination of letterpress printing plates used on an offset process. Letterpress is the oldest form of printing and made its' first mark in history in the 15th Century, when the process was used in the production of the Bible by Johann Gutenburg [2].

Letterpress dominated the print industry until the late 1800s, when the introduction of particularly offset, but also screen and gravure printing in the early 1900s saw greater competition and a down turn in it's use. However, many new printing processes used components found on a letterpress press.

The image plate used for letterpress uses a relief area from which to print. It is the raised image area to which the printing ink is applied before being transferred to the substrate. Typical letterpress configurations are platen, flat-bed with impression cylinder and rotary. The image transfer, although traditionally direct, can also be indirect or offset by using a printing blanket and hence creates the letterset process. The original print plate was constructed with movable metal type placed into a frame known as a chase. This proved very time consuming, especially as the type had to be reversed, so that when printed it would read correctly. The time required creating this plate led to the need for new plate making techniques. Several techniques are used depending on the application.

The first of these is stereotype. This plate is created with the use of a mould of the original image. Molten metal is then poured into the mould to produce the plate, allowing numerous copies of the original mould to be produced. Typically used for the flat-bed presses, they can also be produced to correspond with the rotary cylinder diameter. The second plate type, electrotype, is also produced using a mould. It varies in that the inside of the mould is sprayed with a silver coating, which is then electroplated using either copper or nickel. The plate, once removed from the mould is then filled with lead or plastic for support. The final type of plate used in letterpress is that of the photopolymer. The introduction of this type of plate in the

1960s has almost completely replaced other letterpress plate making methods and has also led to the decline of letterpress as it is known. The creation of the image starts with formation of the back of the plate by exposing the polymer material to light. The material is the turned over and the negative/positive of the image is the place on top and the exposure procedure is repeated. The exposed non-image area is then removed to leave the relief image. The plate is generally backed using aluminium or steel. Developments such as Computer-to-Plate (CTP) technologies can also be used to create plates on a photopolymer material.

As shown in Figure 1.2, the Printing section comprises three different parts, base coating, print and over varnish. Each of these will be explained in detail below.

1.3.3.2 Base Coating

The base coat is applied in order to produce a suitable surface on which printing can take place. The base coat is applied using a simple nip contact as shown in Figure 1.3a at the beginning of the decoration process as shown in Figure 1.2. A picture of the base coater can also be seen in Figure 1.3b. The base coat is generally white or clear depending on the customer requirements. The thickness of the coating varies, the white base coat is generally 10-15μm thick, which produces a strong base colour and eliminates the colour effect of the aluminium. A clear base coat only requires a thickness of 5μm. The base coat is applied in two full rotations of the can.

Once the base coat has been applied, the cans are passed through ovens at approximately 120°C for roughly 10mins (dependent on production speed) to dry the coating in preparation for printing.

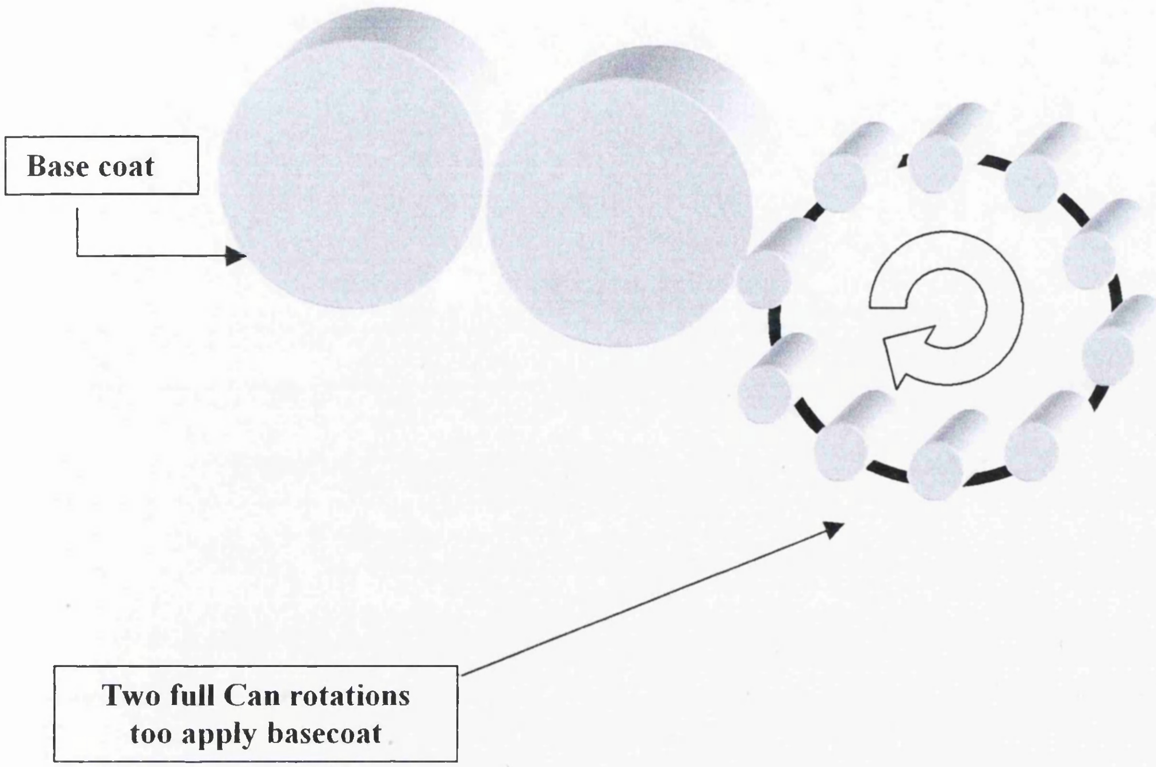


Figure 1.3a Base coat Application (Simple Nip Contact)

Figure 1.3b Base coater

1.3.3.3 Printing Press

The letterset or dry offset presses used at Envases comprise six, seven or nine colour units, dependent on the line. The major difference from traditional dry offset printing is that non-process colours are used, rather than the traditional four-colour process printing, due to registration requirements when printing onto a cylindrical substrate. Depending on the number of colours required pre-mixed ink is placed into each colour unit. The pre-mixed ink is formulated on site from a core number of supplied inks. The cans are transferred from the base coating section onto printing mandrels. The mandrels are then brought into contact with the blanket cylinder, at which point the print is transferred.

Unlike regular web presses, where each colour is printed using a separate blanket, the image is built up using just the one blanket, as can be seen in Figure 1.4a, allowing the print to be produced in one rotation of the can. Figure 1.4a displays only one of the inking trains, with the others shown schematically. A picture of the press can also be seen in Figure 1.4b.

The ink is held in the ink duct, which is a trough shaped reservoir, in which the duct roller rotates and supplies ink to the system. To maintain the correct amount of ink flowing into the system, a segmented blade is used. The blade is micro-adjustable at approximately 15mm intervals across the width of the press with a series of screw actuators. This provides an advantage in that the amount of ink across the duct roll can be varied depending on inking requirements.

The quantity of ink supplied to the duct roller is relatively large compared to the quantity of ink required throughout the rest of the ink train. The quantity of ink allowed into the ink train is controlled with the use of the oscillating roller. The oscillating roller controls the flow of ink into the system by moving between the duct roller and the first transfer roller. The timing of the oscillations will vary depending on requirements, but in general the oscillating roller picks up over a quarter of a revolution for every four cans printed. Through an analysis of ink transfer in the train, it can be shown that this oscillatory action prevents the accumulation of ink within the inking train and that the amount of ink held in the roller train will show a cyclic variation under steady printing conditions. From the oscillating roller, the ink is then passed through the roller train. This consists of a series of rubber rollers, which are constantly in contact, allowing simple rolling contacts to be formed. One of the rolling contacts oscillated transversely against the rollers in contact with it, this further aids the even distribution of the ink, as well as stopping the phenomenon of ribbing.

The main purpose of this large number of rollers is to sufficiently 'work' the ink before printing, ensuring the ink has a low enough viscosity in order to print onto the can. The working of the ink at every contact is achieved through shearing of the ink, reducing the viscosity and ensuring the ink is sufficiently sheared by the time it reaches the printing plate.

From the roller train, the ink is then transferred to the printing plate. The printing plate, which is a thin sheet of aluminium-backed polymer, is attached and secured round the plate cylinder. The printing plate incorporates a relief section from which the image is printed. The ink is forced onto the image area of the plate, before being transferred to the printing blanket. The printing blanket is a thin sheet of rubber attached to the blanket cylinder. It is on this printing blanket that the image is built up and then transferred to the can. The transfer of the image is completed in one rotation of the can. This is achieved by applying each colour to the blanket in turn, building up the complete image in one pass. The reason for this method of image transfer is due to the difficulty of ensuring registration if the can was printed using traditional means. The blanket cylinder incorporates two or three blankets depending on the printing press, allowing two or three images to be printed with one rotation of the blanket cylinder. This allows one image to be printed onto a can whilst another is being built-up on the next blanket in readiness for printing onto the next can.

Once the can has been printed, it is dried for approximately 10 minutes at 150°C, before being transferred to the next section.

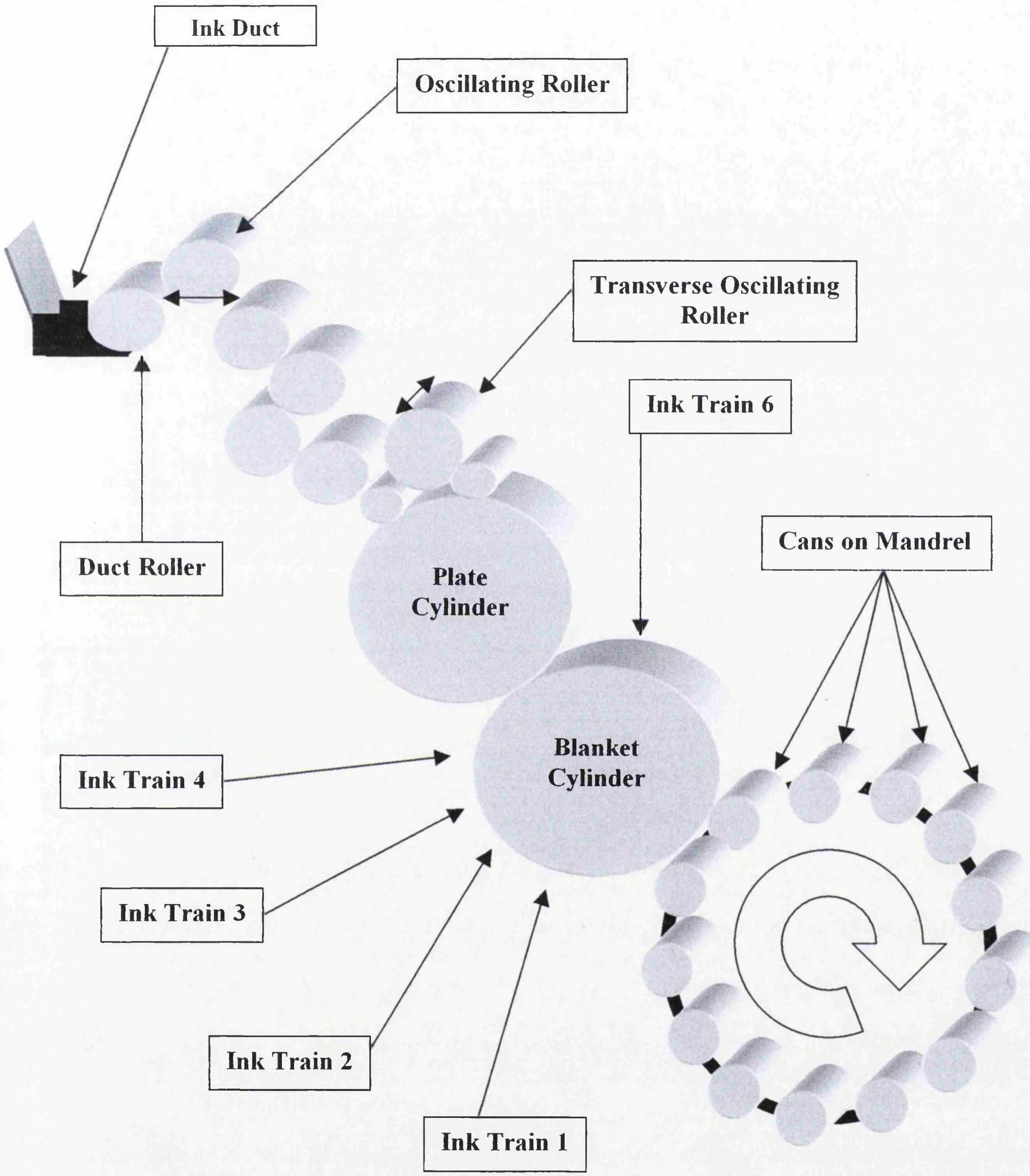


Figure 1.4a Printing Press Schematic

Figure 1.4b Printing Press

1.3.3.4 Over-Varnishing

The finish produced after the ink has been dried is relatively delicate, being easily marked or scratched. To overcome this problem a protective coat, known as over varnish is applied to the can. This over varnish is applied in much the same way as the base coat.

The type of over varnish used is dependent on customer requirements, but is generally semi-mat or clear gloss. The can is once again dried for ten minutes at 120°C, before reaching the necking section.

1.3.4 Necking

This is the final stage of can production, where the top of the can is formed and the neck is developed. The neck is developed in approximately twenty stages until the size of the top is able to accommodate the required aerosol valve (this will be attached after the can has been filled). The necking section also incorporates an embossing facility, allowing shapes to be formed at certain points on the can. Once the can is completed, it is then packed in bundles ready for delivery.

1.4 Thesis Aim & Layout

1.4.1 Aims

The overall aim of the project was to establish a scientific understanding of the can decoration process. Paths for subsequent improvement were identified and pursued. Thus the project was carried out in several stages.

Stage 1 Establish Colour Measurement within the Company.

The first stage was to establish a method of colour measurement that is appropriate for the full range of can decoration used by the Company. This was then used to establish the extent of the current colour variation during production. Once the current process variability had been established, it was then possible to assess the impact of accessible production parameters on performance. This had the aim of highlighting the important parameters and quantifying their effect.

Stage 2 Process Parameter Investigation

It has been understood that there are a large number of variables in printing that can affect the quality of the printed product. With this in mind, it was decided to investigate as many of the variables as possible, be they controllable or non-controllable (i.e. noise parameters). Many of these variables were also monitored in order to find their normal variation during production.

Stage 3 Standardisation

Within this programme, methods of standardising the printing process from pre-press though to production were explored. The successful completion of this stage will ensure better quality production as well as saving production time.

1.4.2 Layout

Although the project has a strong industrial application, a research approach was maintained throughout the work. This thesis reports principally on the research content within the project and highlights findings that have emerged as a consequence.

The work that has been carried out in this project is reported in five chapters, as summarised below.

Chapter 2 describes relevant background material required for subsequent work detailed in the succeeding chapters. Included in this chapter are, colour communication, formulation and its measurement and work previously carried out on the process.

Chapter 3 investigates current process performance and parameter identification and investigation. Detailed descriptions of tests performed and results gained are highlighted. Also included are discussions of the results.

Chapter 4 describes a detailed account of the creation and development of a process specific database required for the utilisation of a colour formulation system.

Also included are the advantages and limitations of such a system when applied to this process.

Chapter 5 includes all conclusions and recommendations drawn for this investigation.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to review the relevant literature. Highlighted below is work previously carried out on this process, as well as similar work from which material has been sourced. Also detailed is the background information concerning several of the measurement techniques used and systems required for the completion of this project.

2.2 Experiments on Letterset and consistency issues

There has been minimal work carried out into the investigation of the letterset process, with very little work focused specifically on the decoration of aluminium aerosol cans. Therefore, there is very little information regarding all aspects of the can decoration process. Also in reviewing the literature, decoration of substrates such as tin was explored [3] and no relevant information was found to be available.

Previous work that has been carried out was done to highlight a suitable colour measurement system for measuring colour on a highly reflective surface and also a limited investigation into process performance. The work was carried out at the University of Wales, Swansea and produced the following findings [4].

The most suitable colour measurement system was that of spherical spectrophotometry, using the spectrally included part of the reflected light.

Further work was carried out to highlight the colour variation during production, as well as the effect of thermodynamic transients on colour. The findings of the work showed that the visible colour of the decorated cans produced by Envases does not appear to be affected by the thermodynamic transients on the press. The largest colour variations measured were all within a ΔE of 2.

This work was only carried out on one of the lines at Envases and used only one can design, incorporating a solid black and brown colour on a white base coat, both of which have been found to be stable colours [4] and did not take into account any other process parameters.

There has been some specific work carried out on the letterpress process, from which the letterset process developed, with regard to process performance. The work studied the 'measurement of ink transfer in printing coated paper', and was carried out using reproducible laboratory printing techniques to identify the effect of major printing variables on ink transfer and print quality in the letterpress printing of black solids [5]. However, since the decline of letterpress/letterset and the increase in printing processes such as offset lithographic and flexographic, research into the process has remained limited. Similar work on other printing processes has included work identifying colour shifts during four-colour printing [6]. Other work into a different process has highlighted the effect that many of the process parameters have on the printed product, such as press speed, temperature and pressure etc… [7]. Although this work is not directly comparable to the process at Envases, many of the experimental techniques and procedures can be adapted and used.

The control of the offset process to minimise the colour variations, which occur during four-colour printing, has been detailed by the preposition that the printing operation can be modelled as a closed loop system [8]. This looked to identify procedures, in flow chart form, for controlling the colour variations inherent to the offset process.

Measurement of ink film thickness printed has also been investigated in the offset process [9, 10]. It details a method for measuring the ink film thickness on paper and the conditions that must be met to achieve acceptable results as well as the variation of printed ink density with film thickness. Work is also detailed on comparative prints made using an IGT printability tester [10].

Work describing specific parameters and measurement methods for use in graphic technology are detailed in International standards [11]. However this standard is intended solely for process control for the manufacture of half-tone colour separations, proof and production prints and therefore concentrates on standard four-colour work. It does highlight the importance of selecting and maintaining a measurement method, thus allowing standardisation.

Relevant work detailing colour specification and tolerances has also been published. This work details tolerances for selected printing processes [12]. Other work has detailed how colours and their tolerances are traditionally established and the problems associated with these method. Also included is an investigation into the use of a colorimetric method along with colour tolerance modelling as a solution in specifying not only the standard colour, but also the maximum and minimum colours based on pre-established colour tolerance limits [13].

2.3 Interactions of light with matter

Reflection from a surface occurs when monochromatic radiant energy, such as light, is incident on a material is partially returned by the material without a change in wavelength [14]. This reflection can be regular, diffuse or mixed.

Colour in the manufacturing industry is usually obtained by applying a dye or pigment to a substrate. The appearance of the surface colour depends on three factors [15]:

1. The nature of the prevailing illumination under which the coloured surface is viewed.
2. The interaction of the illuminating radiation with the coloured species in the surface layers, particularly within the visible region of the electromagnetic spectrum
3. The ability of the radiation that is transmitted, reflected and scattered from the coloured surface to induce the sensation of colour in the human eye.

The visible portion of the radiant-energy spectrum as shown in Figure 2.1 is small. However, it is over this small portion that we are able to perceive colour with the use of the human eye. As with most mediums such as pigments, as energy is applied, a reaction will take place, whereby the medium will be able to absorb some of the incident energy. It is the ability, or inability, of the medium to absorb the radiant energy that gives rise to its perceived colour. This highlights the importance of using an energy (light) source, which is able to produce the required radiant energy for correct (depending on requirements) colour perception.

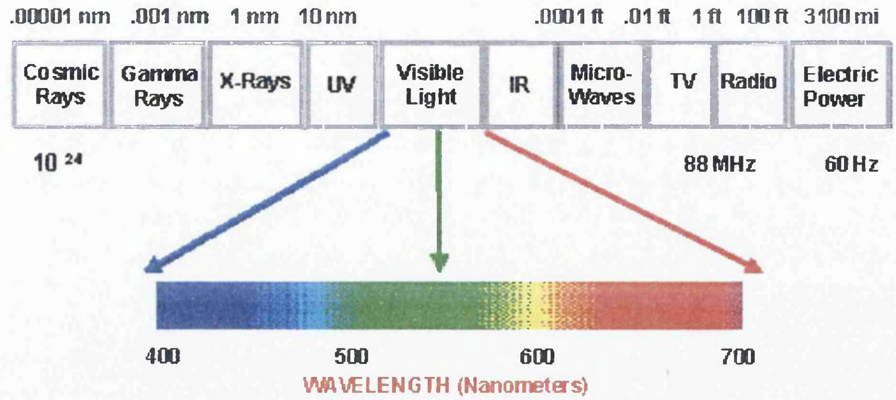


Figure 2.1 Visible spectrum

If a beam of light is incident on a painted surface it will undergo refraction and reflection as it meets the painted surface as shown in Figure 2.2. The refracted beam will actually enter the surface and in doing so will be scattered and absorbed by the paint, thus giving the underlying colour of the surface. The reflected light on the other-hand will affect the visually perceived colour. It must be noted that other factors such as interference or diffraction of light can also give rise to perceived colour.

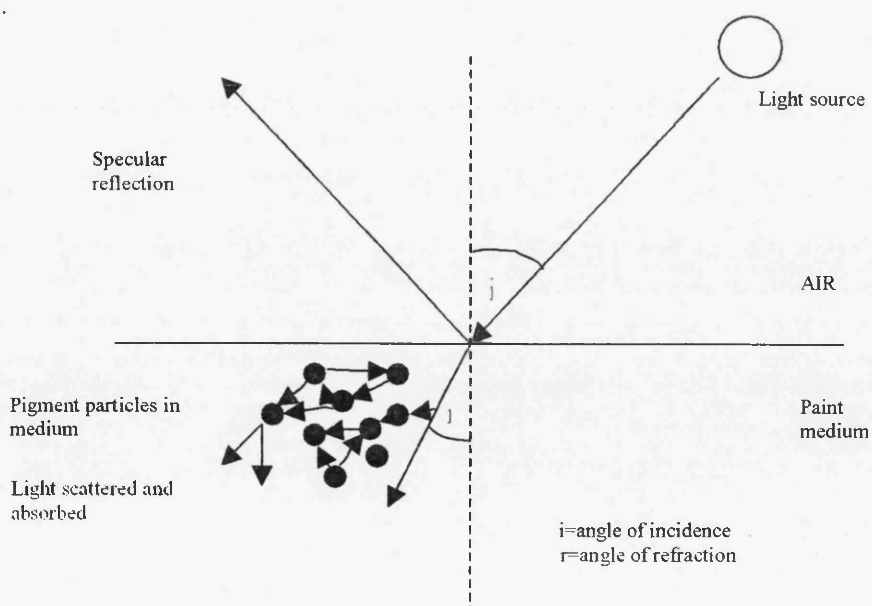


Figure 2.2 Interaction of light at medium surface

From figure 2.2, the various interaction of light with a medium can be identified. The specular reflected light from the surface, which commonly accounts for 4% of the total reflected light at normal angles [15], will be the same as the incident light, as light needs to undergo absorption before it changes appearance. This reflected light, as previously mentioned will affect the visually perceived colour.

The light that is not specular reflected will be refracted at the medium surface. This light will then be scattered throughout the medium in all directions by the pigment particles within it. A large proportion of this light will then return to the surface of the medium producing the diffuse reflection.

The final interaction of light with the medium is absorption. If the medium contains coloured pigments, then as well as the scattering of the light the pigment particles will also absorb the light. The light absorbed will not be reflected and will therefore largely dictate the colour of the medium.

The combination of both absorption and scattering of white light is what many mediums, especially those opaque in nature will diffusely reflect to produce their colour. This combination is known as the Kubelka-Munk analysis. This analysis will be detailed below and will be further discussed for the colour formulation theory detailed later in this Chapter.

The Kubelka-Munk considers the incident and reflected light separately as shown in Figure 2.3.

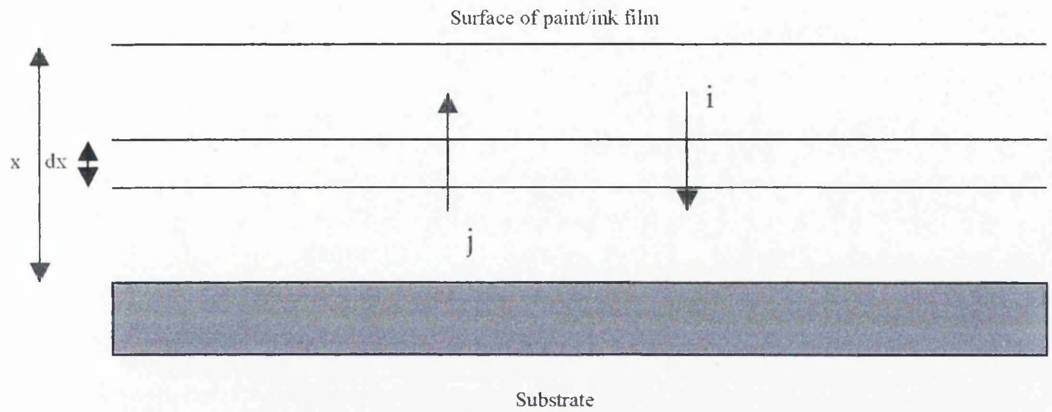


Figure 2.3 Incident and Reflected light on a layer

The layer shown as dx in the above figure represents a thin layer that is small in comparison to the overall thickness of the paint/ink layer, but is large compared to the pigment particle size. The incident and reflected light are considered as two separate fluxes of energy, identified in figure by i and j respectively. The coefficients of absorption and scattering are represented by K and S respectively, so if considering light through the small layer dx.

The downward flux I is:

Decreased by absorption = -KI dx

Decreased by scattering = -SI dx

Increased by backscatter = +SJ dx

Therefore:

$$dI = -KI\,dx - SI\,dx + SJ\,dx \quad = \quad -(K+S)I\,dx + SJ\,dx$$

The upward flux J is:

Decreased by absorption = -KJ dx

Decreased by scattering = -SJdx

Increased by backscatter = +SI dx

Therefore:

$$dJ = -KJ\,dx - SJ\,dx + SI\,dx = -(K+S)J\,dx + SI\,dx$$

The solution to these differential equations by applying suitable boundary conditions [16] gives the commonly used and general Kubelka-Munk expression:

$$K/S = \frac{(1-R_\infty)^2}{2R_\infty}$$

Where $R_\infty = J_0/I_0$ is the reflection factor at the surface for the sample of infinite thickness.

The solution shown will be expanded to illustrate the dependence of reflection on pigment concentration in section 2.5.2, where the K, S values provide functions, which are related to the concentration of pigments in solids.

2.4 Colour Measurement

2.4.1 Introduction

It is important to have a measurement framework within which all colours can be defined quantitatively. In order to communicate colour, it is important that the three components of colour, illuminant, object that is illuminated and the observer, are all available. This is the basis of how colour communication is achieved today [17]. There have been several methods of colour measurement devised over the last one hundred years or so, of which two are widely used in today's print industries.

2.4.2 Colour Communication

From the early days of colour matching, which involved observers matching a predetermined colour using red, green and blue light, colour communication has undertaken significant development. It was not until the 1930's that the Commission Internationale de l'Eclairage (CIE) replaced the relatively simple R, G, and B values with a new set of tristimulus values X, Y, and Z, where Z represents the lightness. It was still based on the fact that white light could be created from red, green and blue light, but had a correction factor so as to eliminate the possibility of negative values for all colours. At this point, the CIE also suggested that the angle of observation for these values was 2°. This was recommended as the colour viewed depends on the angle. From these tristimulus values, the CIE recommended the use of the CIE xyz chromaticity co-ordinate system to define and communicate colour, as shown in Figure 2.4.

In 1964, the CIE specified another colour space system, based on the CIE xyz system, but replaced the 2° observer with a 10° observer, which allowed colour to be more easily discriminated. This was updated in 1976 to the colour systems that are still used in the print industry worldwide.

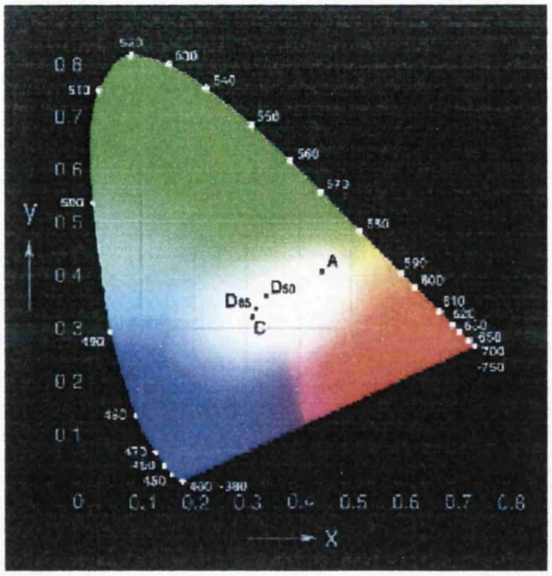


Figure 2.4 CIE 1931(x, y) Chromaticity Diagram

2.4.3 Uniform Colour Spaces

The CIELab 1976 colour specification replaced the previous CIE xyz system and introduced a new colour chart as shown in Figure 2.5.

The new system was more uniform, in that an equal change in measurements gives an equal change in perceived colour. A non-linear scale was also recommended to quantify lightness so that the measurements correlated more closely with the visual assessment. However, it is still only 75% in agreement with the visual assessment [18], the reason will be highlighted below.

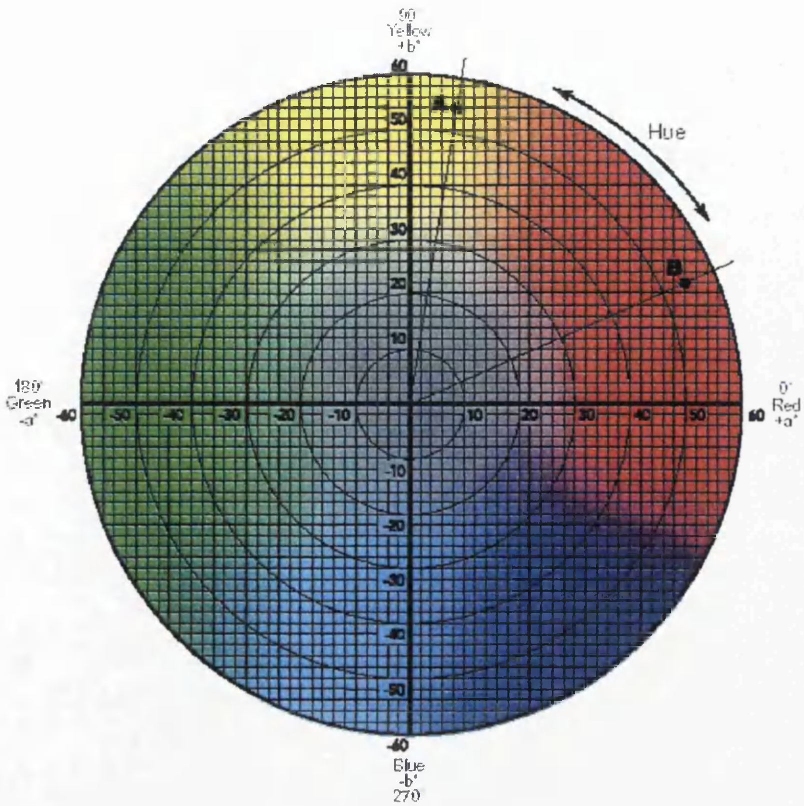


Figure 2.5 CIE Lab Colour Chart

The CIELab system allowed the introduction of colour difference formula, thus allowing differences between colours to be quantified. These have been progressively improved to correspond better with visual perception. The initial colour difference formula, known as CIE ΔE 1976 was used to show the difference between colours within the colour space, based on the fact the distance between two samples could be calculated using the different Lab values. Using the differences in the component data between two samples, it was possible to calculate the total colour difference as shown below.

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

At the same time, another set of tri-stimulus values L, C and h were also created. These values relied on the same colour-space as the Lab values, but were a polar co-ordinate system as opposed to a Cartesian system. The lightness value (L) is the same for both, but the C value represented the chroma of the colour (strength) and the h represented the hue angle (actual colour). However, as the hue value was an angular measure, it could not be combined with the L and C components as easily and therefore the value shown below was used in calculations for the ΔE value.

$$\Delta H_{ab} = [(\Delta E_{ab})^2 + (\Delta L)^2 + (\Delta C_{ab})^2]^{1/2}$$

$$\Delta E = [(\Delta L)^2 + (\Delta H_{ab})^2 + (\Delta\ C_{ab})^2]^{1/2}$$

Although the Lab and LCh systems could describe the same position within the colour space, a new colour difference formula was accepted by the CIE and was published as the CIE_{94}. It was based on the polar co-ordinate system and was a simplified version of the previous CMC colour difference formula [17]. The system was non-Euclidean and eliminated the inherent problems with the original colour difference formulations, which suggested that colour differences could be represented as simple distances in a three-dimensional space. The new system was created to highlight and discriminate between smaller colour differences, i.e. if CIELAB ΔE is less than 5 [19]. This new formula for the calculation of ΔE also minimised the errors described by the by the Lab colour difference, whereby pairs of very similar high chroma colours produce very large numerical differences. The parametric factors, k_L, k_C and k_H and the weighting functions S_L, S_C and S_H in CIE_{94} were introduced to achieve this improvement [20]. This new colour difference system ensured that the values gained were 95% in agreement with the visual assessment [18].

2.4.4 Spectrophotometry

Spectrophotometry is used in the printing industry in order to obtain numerical values for colour. There are several types of spectrophotometers available, which vary dependent on the optical configuration. The most common type of spectrophotometer has optical configuration specified as 0°/45°. The alternative is a spherical spectrophotometer.

Both types of spectrophotometer work to the same principles, where by the light emitted by the spectrophotometer is both absorbed and reflected by the sample, the result of which provides reflectance data from the sample over the visible wavelength, known as spectral data as shown in Figure 2.6.

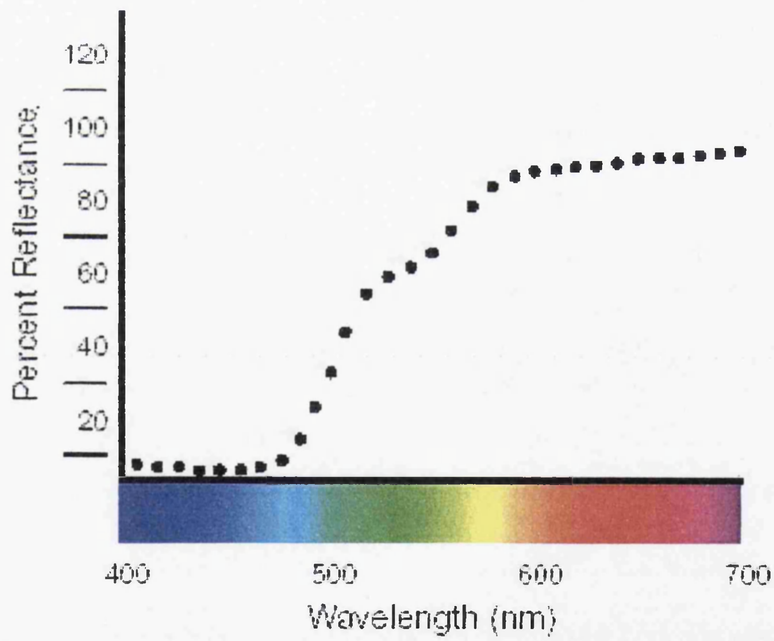


Figure 2.6 Spectral reflectance Curve

The reflectance data is then transformed by the spectrophotometer by applying a number of filters. The first of these will be that of the illuminant filter as shown in Figure 2.7 and secondly the observer filter as shown in figure 2.8. With these filters applied, it is possible to obtain the X, Y, and Z values, thus allowing other colour space values to be calculated. Most spectrophotometers will display all colour space values (CIELab, CIELch etc.) described above, using various illuminants and both observer angles, depending on requirements.

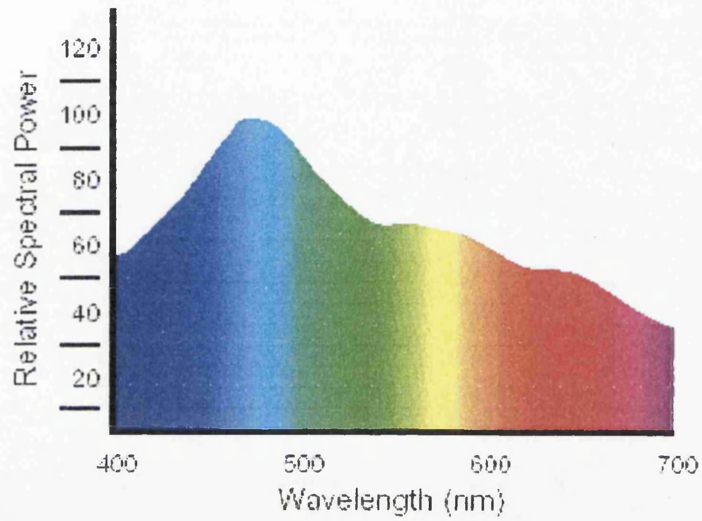


Figure 2.7 Daylight Standard Illuminant (D_{65}/10°)

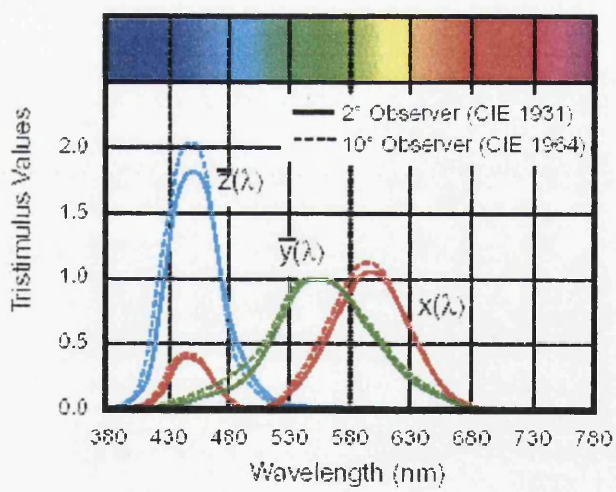


Figure 2.8 CIE 2° and 10° Standard Observers

The 0°/45° spectrophotometer illuminates the sample at 45° and then collects the light vertically at 0°, as shown in Figure 2.9. The light collected is then detected at a set number of positions through the visible spectrum, usually 380nm to 730nm in intervals of 10nm, using a CCD array. This produces the reflectance data from which all subsequent calculations can be made. The configuration of the 0°/45° allows both densitometric and colour space values to be calculated.

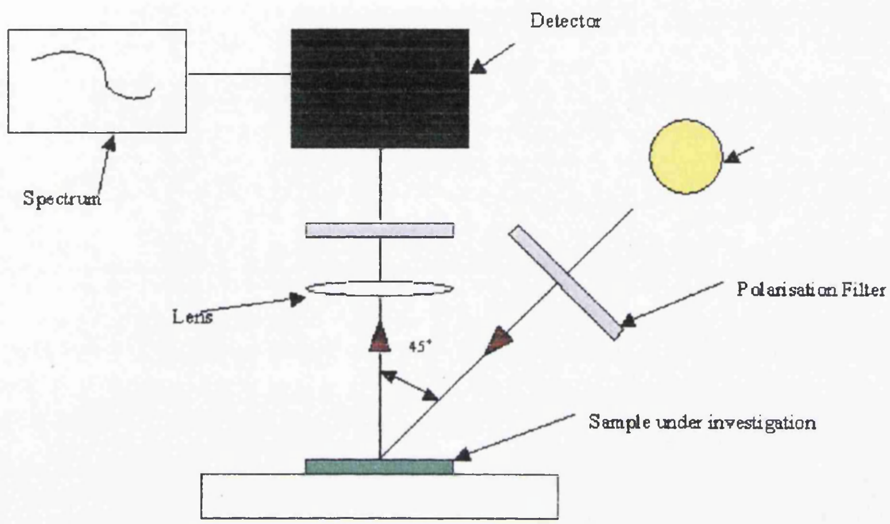


Figure 2.9 0/45° Spectrophotometer

The spherical spectrophotometer is designed to measure both diffusely and specularly reflected components of the illuminant. A schematic of the spherical spectrophotometer can be seen in Figure 2.10. The light from the illuminant is reflected around the sphere, producing a diffuse light source. The reflected light is collected at 8° to the normal and is detected using a CCD array. The reflectance data is then used for subsequent calculations.

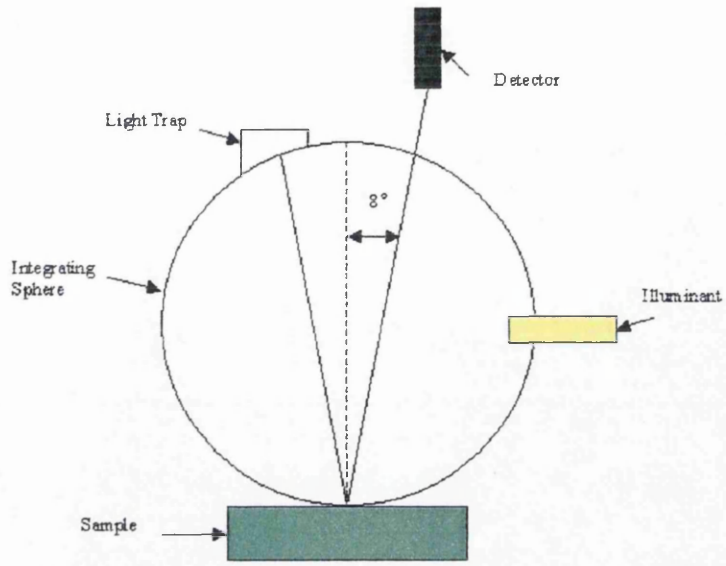


Figure 2.10 Spherical Spectrophotometer

The advantage of using a spherical spectrophotometer is that both the specularly included and specularly excluded measurements can be taken. The specularly included measurements are calculated using both the diffuse and reflected light, whereas the specularly excluded measurement is achieved using just the diffused light.

Spherical spectrophotometers are unable to make densitometric measurements. They are however ideally suited to measurement on metallic or uneven surfaces such as aerosol cans.

2.5 Colour Formulation

Printing may be achieved using process colours in which the image is separated into Cyan, Magenta, Yellow and Black or it may be achieved using non process colours in which the specific colour is prepared as an ink for the process.

Therefore, as with any non-process colour printing, the colour required for the print is pre-mixed or formulated from a palette of commercially available inks prior to production.

2.5.1 Traditional formulation

Traditional methods of colour matching required the use of a Pantone book [21] and skill of a colour-matcher. The PANTONE Colour Formula Guide features a total of 1012 colours printed on coated and uncoated stock, Figure 2.11 [22]. The colour required for production is matched as closely as possible, with the use of the colour-matchers skill, to the nearest pantone colour. The pantone colour is then described by its base formulation, e.g., 2 parts yellow, 3 parts green, 1 part white, and the colour-matcher will then use this as a starting point in order to formulate the ink. In some cases, a sufficient close match can take in excess of ten attempts. This can represent an extreme waste in terms of both materials and time.

Figure 2.11 PANTONE Colour Formulation Guide

Colour formulation using the pantone colour formulation guide is a very crude method, in which there are many inherent problems. The problem is the way in which the pantone guide is produced and this raises three main points. The first is that the pantone book is only produced on two types of paper, coated and uncoated and it is well known that different substrates give a different appearance for notionally the same colour. This means, the formulation listed in the book will only appear the same when printed onto a similar white-paper substrate. Another simple problem is that of ink types. Although the pantone book recommends the ink colours and quantity required to formulate the particular ink, it is not specific to the base inks stocked by individuals, which are sure to vary between suppliers. This will almost certainly mean the suggested formulation will not match the required colour, leaving it to the skill of the colour matcher to correct the formula. The final problem is simply the consistency of the pantone book. As with most printing processes, there will be variation in printing the pantone book itself, no two will be identical. This could mean the colour matcher is formulating to a different colour to what the customer requires. This can be further affected by the use of old or faded copies of the guide.

Even though the pantone book is a useful guide, it is restricted to this role. It cannot be used for consistent and quick ink formulation without the skill of an experienced colour matcher.

2.5.2 Formulation systems

The creation and continued development of the colour-space system and spectrophotometry has allowed new means of colour formulation to be developed. As with colour measurement, the principle behind a colour formulation system is to remove human colour perception from the process. Some of the advantages of the system are that, the colour matching experience is not essential in formulating the correct ink and the formulation is specific to the process, inks, substrates and ink thickness.

The purpose of a colour formulation system is to match, under the same operating conditions (illumination and observation), using a suitable formulation, a colour when applied to a substrate. The Kubelka-Munk theory, as described in section 2.3, first developed in the mid 1930s [16] was the base used for the majority of formulation systems used in industry today.

Two main models are required for the successful colour match calculations to be carried out, these are:

a. An optical model that relates the reflectance spectrum of the surface to the concentration of the components in the formulation, the thickness of the coating layer and the reflectance spectrum of the substrate.

b. A colour model relating the reflectance spectrum to colour appearance.

The first of these is satisfied by the Kubelka-Munk theory and the second by the CIE colour models.

As previously shown in Chapter 2, section 2.3, the interaction of light with matter occurs due to several processes. Also highlighted was the Kubelka-Munk theory and the general expression for an opaque layer.

However, not all printing applications use opaque inks, and many, if not most use semitransparent inks or a combination of both. It is therefore important to include an analysis that takes into account that for a semitransparent layer some of the light will have not only been directly scattered from the pigments, but also reflected by the substrate back through the layer.

The kubelka-Munk theory provides an answer by establishing the optical properties of the layer and then determining the effect of the substrate beneath it. This requires defining, the transmittance, reflectance and absorbance of an isolated layer, as well as the reflectance properties of the coating on the substrate.

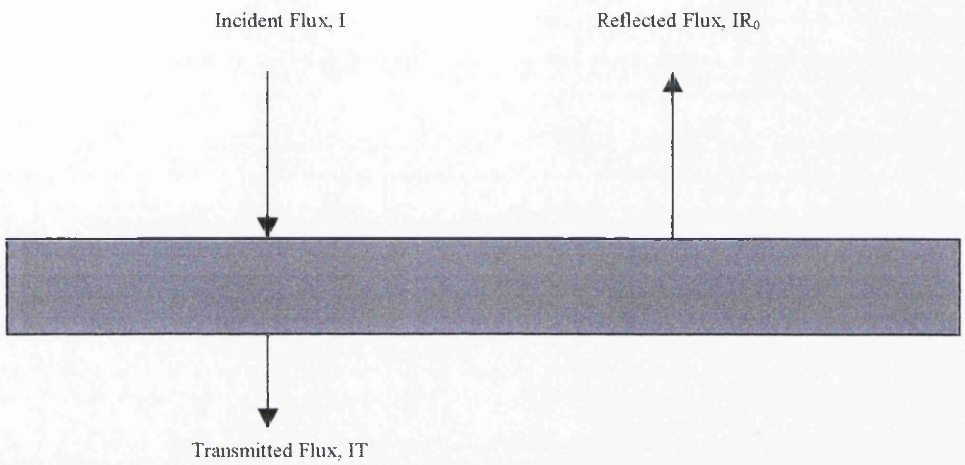


Figure 2.12 Reflectance and transmission of an isolated layer

From Figure 2.12 and the application of the kubelka-Munk theory, it is possible to attain equations relating the Reflectance R_0 and transmittance T in terms of the kubelka-Munk absorption and scattering coefficients K and S and the reflectance of and opaque layer R_∞, as follows:

$$R_0 = R_\infty \left[\frac{1 - \exp(-2Z)}{1 - R_\infty^2 \exp(-2Z)} \right]$$

$$T = (1 - R_\infty^2) \left[\frac{\exp(-Z)}{1 - R_\infty^2 \exp(-2Z)} \right]$$

Where Z is defined as:

$$Z = D[K(K+2S)]^{\frac{1}{2}}$$

and is a measure of the optical thickness of the layer, in which D is the physical thickness of the layer.

The next phase is to define the properties of the coating on the substrate, which introduces two more reflectance terms R_g, the reflectance of the substrate and R, the reflectance of the entire system. In order to obtain suitable equations for the reflection of the whole system, as previously mentioned the substrate and layer should be separated, as shown in Figure 2.13 below.

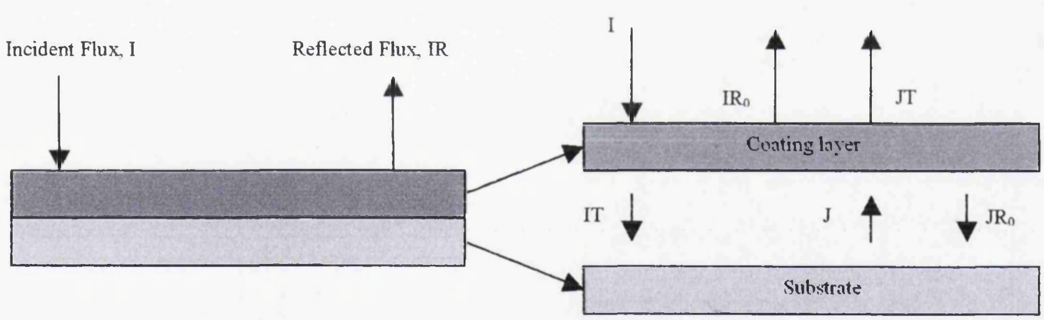


Figure 2.13 Forming an isolated layer

From Figure 2.13, it can be seen that a second flux J is introduced due to the reflection from the surface of the substrate. This second flux will also undergo reflection and transmittance though the layer. However, it is possible to relate flux J to I by the introduction of the substrate reflectance R_g [16]. Solving using the Kubelka-Munk theory gives the reflectance of the composite layer as:

$$R = R_0 + \frac{T^2 R_g}{1 - R_g R_0}$$

Using all four equations set out above, the solution using the kubelka-Munk theory for a semitransparent layer is complete. The first 3 equations give the relationship between K, S and the reflectance and transmittance of an isolated layer and the last equation relates these to the composite layer (coating and substrate). Further simplification by defining constants can be achieved, in order to reduce the combined equation [16].

If more than one colorant is used in layer as with many formulated inks, then an approximation of the resulting scattering and absorption can be given by the sum of the individual values, as shown below:

$$K_{layer} = K_1 + K_2 + K_3$$

$$S_{layer} = S_1 + S_2 + S_3$$

The Kubelka-Munk theory detailed above and in section 2.3 only takes into account the scattering and absorption of the light reflected from a layer, and does not make allowance for the partial reflectance of the light at the air to layer interface. This partial reflectance will occur as the light enters and leaves the layer due to the different refractive properties of the air and layer. The equation used for calculating the partial reflection is known as the Saunderson equation[16,17].

The use of the Kubelka-Munk theory for formulation systems depends entirely on the ability to determine the K and S values. This is achieved by creating a database of calibration panels encompassing all colorants used. The accuracy to which the database is produced will directly affect the quality of the colour formulations [23]. The calibration panels are then measured using a spectrophotometer. In order to meet the assumption made in the Kubelka-Munk theory, which states 'the sample should be illuminated with diffuse light, that is, the light incident on the surface should be of the same intensity from all directions' [16], as closely as possible a spherical spectrophotometer will give the best results, due to the diffuse light it produces.

The calibration panels required for an opaque and a semitransparent layer will vary due to the fact the opaque layer relies on the ratio of K to S and not the absolute values as with the semitransparent layer.

The ratio of K to S for opaque layers can therefore be found by determining the values relative to a standard, which, in most cases is a standard white formulation. This requires panels to be produced that include the colorant only, white only and a combination of the two at varying concentrations. The database requires the mixing of the white and colorant in different strengths so it is able to characterise the absorption and scattering of each component at any concentration.

For a semitransparent layer, the values of K and S may be calculated from a series of prints at a fixed layer thickness on one or more substrates. This is due to the fact that the equations used to determine the values required include R_∞, the reflectance of an opaque layer of ink. Achieving an opaque layer using semi transparent ink is difficult as a layer printed at high thickness may take time to dry and in doing so crack or still not be opaque. Combined with the fact the reflectance measured for a true opaque layer may not have any relevance when predicting the reflectance in a semitransparent formulation system. Therefore, to solve the problem panels are produced which incorporate the same layer thickness over a white and black substrate. The purpose of the white and black is to represent the reflectance from the substrate surface incorporated into the Kubelka-Munk theory for a semi transparent layer. The white represents the full reflection from the substrate surface and the black no reflection.

In order to calculate K at varying concentrations of the colorant in a layer, the colorant is diluted using what is generally known as a transparent white to give a series of concentration levels similar to that for an opaque application. A detailed description of the production of the calibration panels can be found in Chapter 4.

The formulation system will use the calibration panels to match a specified target colour. This is achieved by selecting colorants, calculating the required quantity of each, summing the contribution of the absorption and scattering from each of the colorants in the formulation. The reflectance spectrum is then calculated by working the Kubelka-Munk theory inversely and putting into effect the Saunderson equation to finally give the colour coordinates of the recipe. This can then be compared to that of the original target.

There are two common methods used for match prediction, spectrophotometer curve matching and colorimetric matching [16]. However, as previously mentioned for a semitransparent system, the reflectance depends on the values of K and S and not their ratio. Using spectrophotometer curve matching, it is not possible to obtain R_∞ for a semitransparent layer and therefore matching equations cannot be developed to satisfy both opaque and semitransparent layers. It is therefore the colorimetric match prediction method that is used to satisfy for both opaque and semitransparent layers.

Colorimetric match prediction works by assessing the effect varying the concentrations of the colorants has on an initial recipe, until the colour coordinates of the recipe match those of the target.

2.6 Closure

The preceding sections have given a detailed description of techniques, processes and systems required for the successful completion of the project. Their application will be used to establish process behaviour and consistency and this investigation will be reported in the following chapters.

CHAPTER 3
PROCESS CONSISTENCY

3.1 Introduction

The purpose of this Chapter is to identify the current process performance and capabilities. This involved the identification of parameters that may have an affect on the performance and suitable measurement techniques to measure their impact. Also included are detailed investigations into the effect of these parameters and the implementation of solutions and procedures to reduce their impact.

3.2 Process Performance

Before assessing any manufacturing process, it is important to identify the current position, which any investigation should try to improve on. Without knowing the current process capabilities, there is no way to know whether the work that has been carried out has in actual fact helped. Therefore, an investigation to identify the current colour variation and production capabilities on all production lines was carried out. This led to simple procedural improvements to minimise colour variations and hence improve product quality.

3.2.1 Colour Variation

Within any printing process, there will be inherent process variations, which will affect the colour of a printed product. Any large colour variations during a print run may cause the customer to reject the batch. Increasingly many customers specify a tolerance (in numerical terms - ΔE), within which production must be kept. If production exceeds these limits, they have a valid reason to reject or negotiate a price reduction. This highlights the importance of knowing the process capabilities, because if the tolerances are set too tightly, then there is no way of maintaining the quality levels set and if it is set too loosely then product quality is compromised.

As mentioned in Chapter 2, the use of spectrophotometry allows colour variations to be quantified, thus quantifying the working limits. It can therefore, be used to identify the current process capability and performance. This was achieved in two ways. Firstly the colour variations that occur across the whole print run were monitored to establish any process drift. Secondly any cyclical variations from can to can were identified to establish short-term variability and sample size required to identify the longer-term variations. It has been shown that cyclical variations occur in offset printing [7]. This has been traced to the mechanical design of the press. Since similar design principles are employed in letterset can decoration, similar variations may be anticipated.

3.2.2 Print run variation

The variation throughout a print run was carried out on all four lines, thus allowing the comparison of consistency across all lines to be identified as well as any production drift.

In an industrial environment, it was important that a single measurement geometry was used to limit any confusion or measurement mistakes that may otherwise become common place. Therefore, all measurements were taken using the GretagMacBeth color-eye 7000A spectrophotometer in SI (Specularly Included) mode. Although there was no correct or incorrect measurement mode, the SI mode was used for the following reasons. Firstly the majority of the work to be presented was comparative and therefore samples are generally compared like with like. Also, the majority of work produced at Envases at the time was that of transparent colours on a silver base or high gloss colours. The spectral reflectance would therefore have an effect on the perceived colour or product, as shown in the samples measured in Appendix 4. These samples display the increased reflectance taken for each sample in the spectrally included mode and the associated lightness, chroma and hue values. It was decided that as the samples were generally glossy in nature, that the associated increased reflectance in the included mode represented this gloss effect and would therefore be used.

The spectrophotometer had been modified to accept and seal onto a cylindrical surface allowing colour measurement on a can to be taken. A picture of the spectrophotometer showing the can holder can be seen in Figure 3.1.

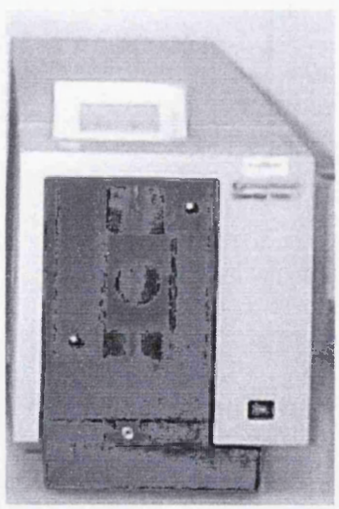


Figure 3.1 Spectrophotometer with can adapter

The measurement aperture used was as small as possible (8mm by 4mm) due to the fact that if it is larger, due to the curved nature of the aerosol cans, light from the spectrophotometer would be able to escape, therefore not allowing suitable results to be attained. The illuminant and observer were standardised to D50 and 2° due to customer requirements for all subsequent measurements. Measurement procedure was also standardised, ensuring results were taken from an average of three measurements per can, taken in similar positions dependent on print design. This served the purpose of allowing any erroneous measurements due to incorrect location of can to be observed and eliminated. Finally all delta E variations were calculated using the ΔE94 equations.

Identification of any cyclic variation was carried out, i.e. can to can variation. It is this that determines how narrow the tolerances should be set, as it identifies the process capability. Unlike production drifts, it is very difficult to eliminate these variations. To identify these frequency variations, 64 consecutive cans were measured. Fourier analysis was then used to display the power spectrum and any dominant frequency. A typical example of the results is displayed in Figure 3.2. This was once again carried out on all lines for varying colours and coverage areas.

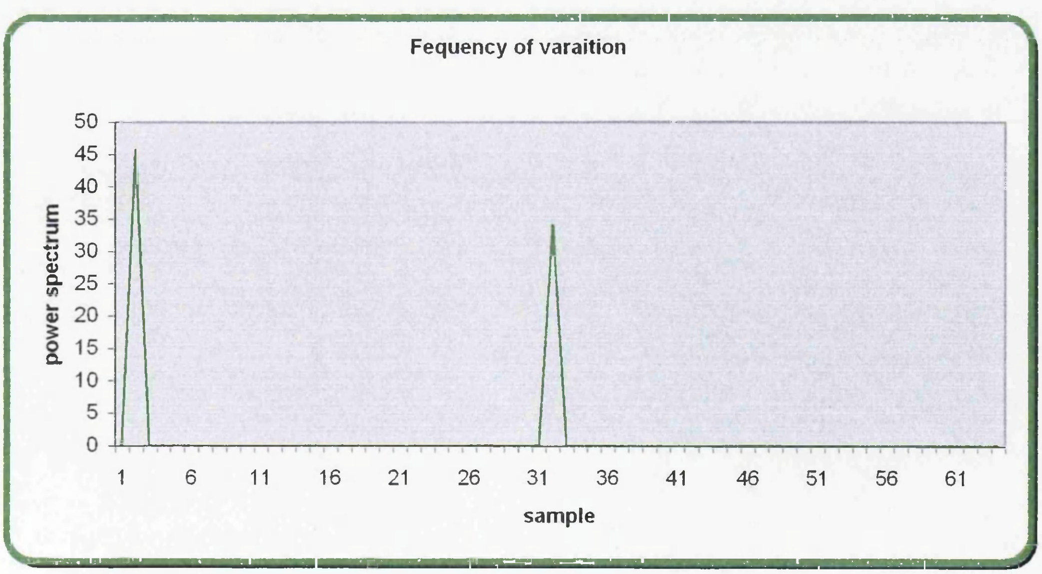


Figure 3.2 Frequency of colour variation

As shown in Figure 3.2, the typical frequency of variation was approximately every 2 cans. This meant a sample size of five cans could be used to obtain a suitable average for subsequent measurements.

Identification of production drift was achieved by collecting five cans at fifteen minute intervals throughout the print run for several designs on each line. The average colour of these five cans was then used and compared to the standard to which production should be measured. These results were then plotted allowing any trends or drifts to be identified. The results of this can be seen in Figures 3.3-3.9 below.

The results gained from these current process performance measurements can then be used to set acceptable tolerances and identify areas for improvement.

Line 4

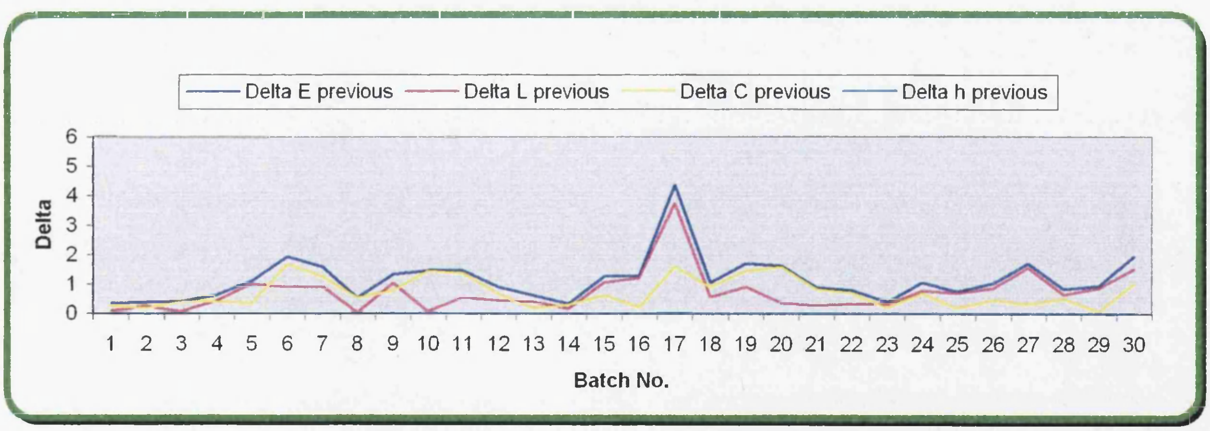


Figure 3.3 Performance – Image : Veet

Line 7

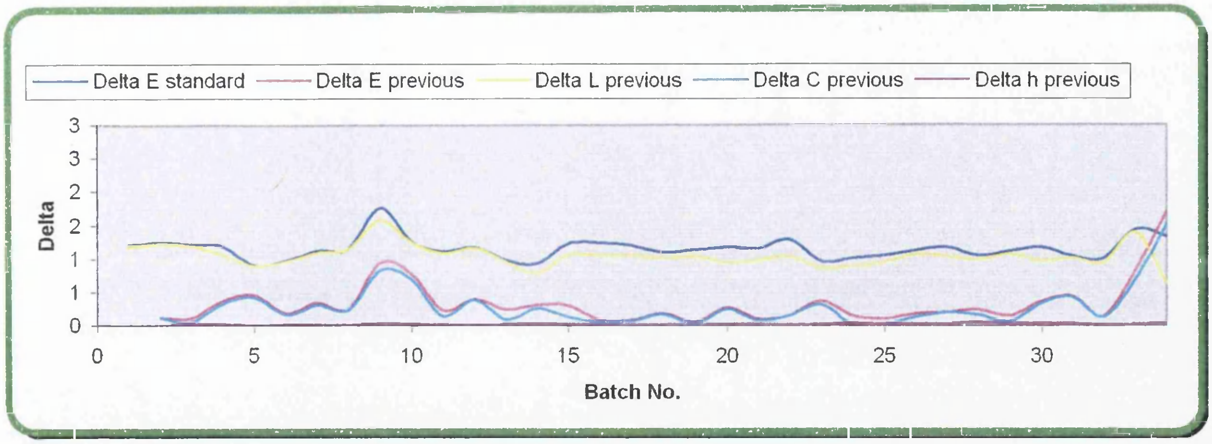


Figure 3.4 Performance - Image : Fcuk

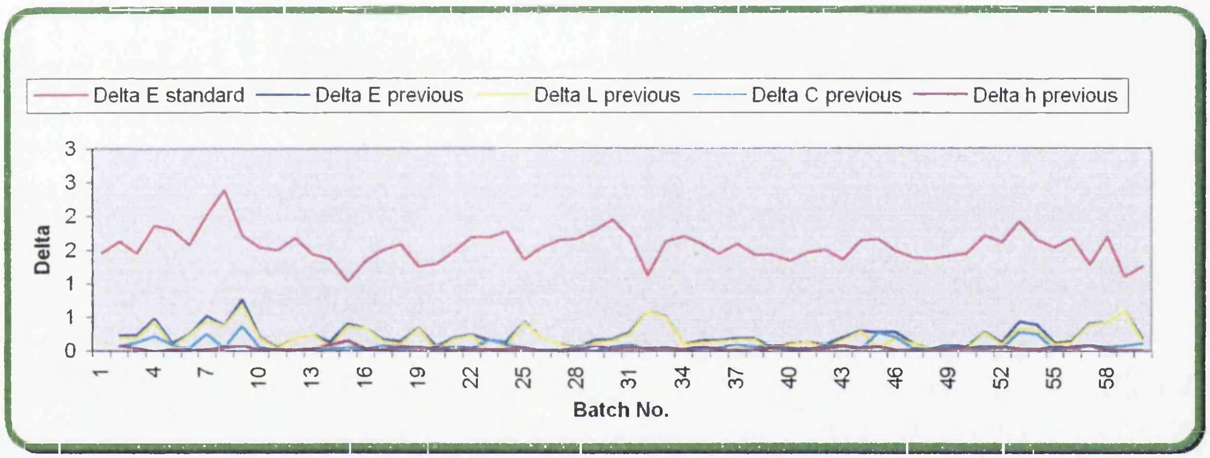


Figure 3.5 Performance - Image : Lynx Voodoo

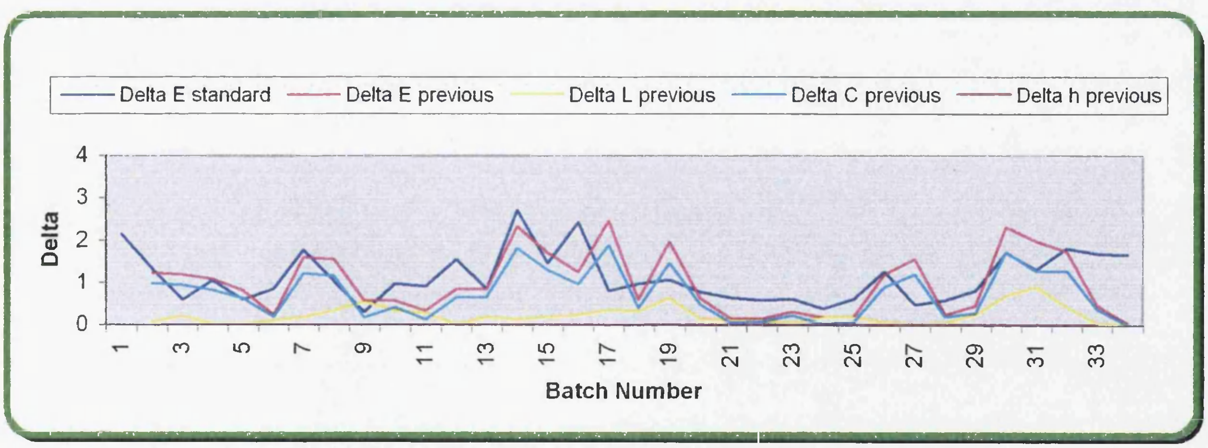


Figure 3.6 Performance - Image : Old Spice

Line 8

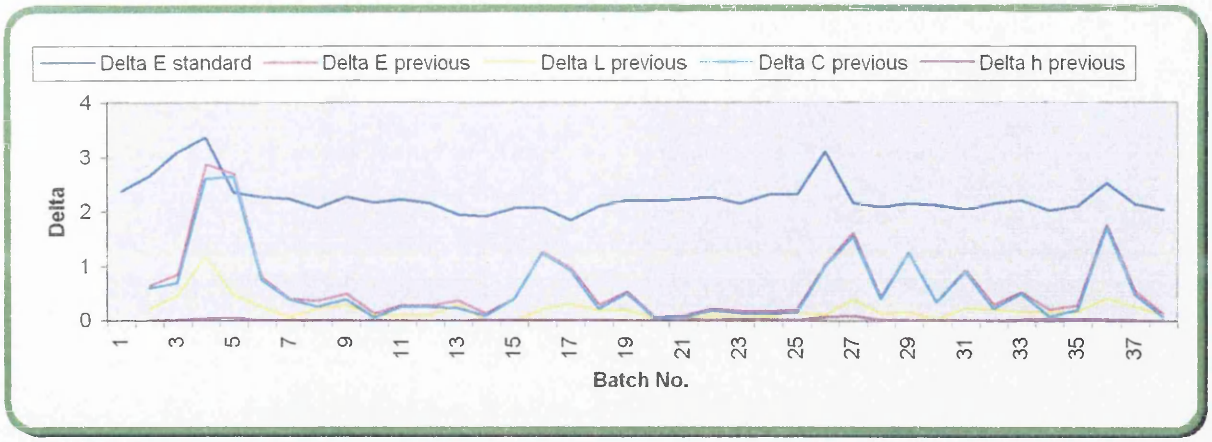


Figure 3.7 Performance - Image : Fcuk

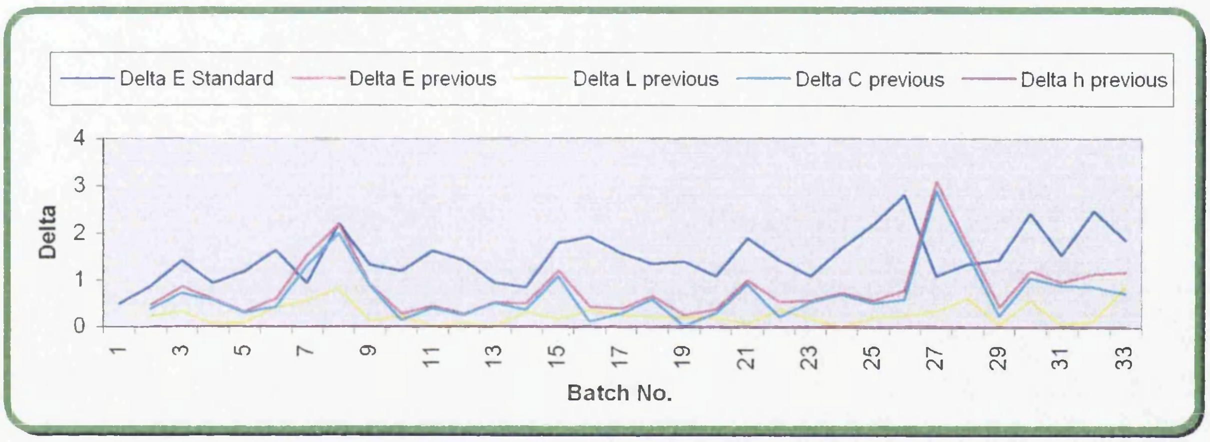


Figure 3.8 Performance - Image : Toni & Guy

Line 9

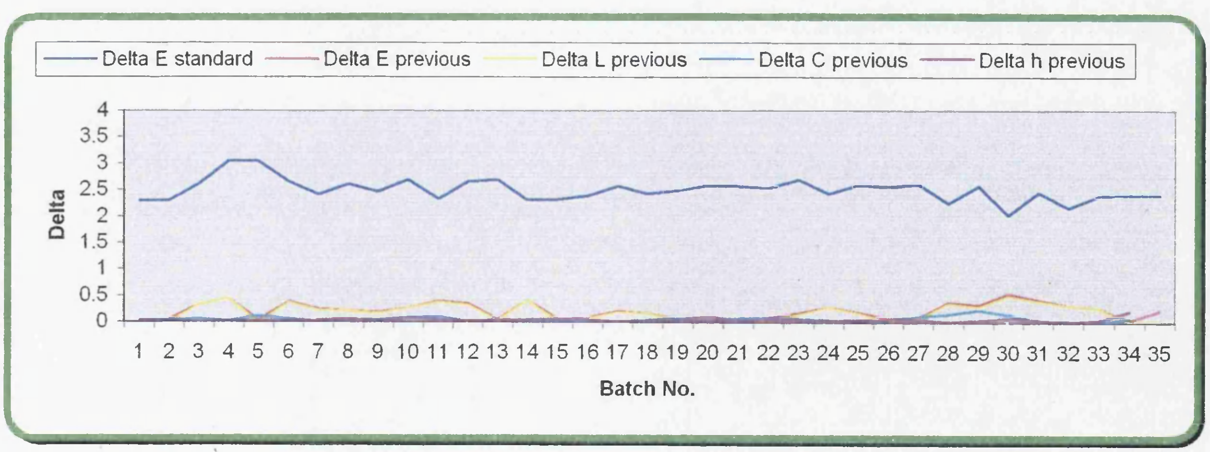


Figure 3.9 Performance - Image : Lynx

The results displayed above highlight the current consistency of the printing process, which, as shown, varies depending on line and print design. In general, the process was very consistent throughout the measurement periods. The results displayed across all lines also show that the variation in colour is limited to the two colour components, the lightness L and the Chroma C, with the majority of the colour difference begin attributed to one or the other depending on the design. This is to be excepted when comparing pre-mixed non-process colours as the hue should not fluctuate as the ink does not change. The variation in colour will only arise due to variation in the ink film thickness, which will be discussed in further detail in section 3.3. For this reason, some of the work detailed in this report is compared solely in terms of ΔE.

The results gained from Line 4 were limited due to the can designs run on that machine. Very few of the designs had an area of print large enough for suitable measurements to be taken (had to be larger than the spectrophotometer aperture size), limiting the results to those of the Veet blue. The results displayed are only for colour changes from batch to batch and not the colour variation compared to the standard. The reason for this is that although a standard can was available, in the process of preparing it for the triptico[1], the area suitable for measurement had been removed. However, the results displayed show minimal colour variation throughout production and only once a variation of over $\Delta E = 2$, with the L component displaying the majority of the variation at this point. The reason for this jump could be due to many parameters including press stoppages, press changes or an erroneous measurement, and without further information it would be impossible to identify its cause. Although

[1] Triptico means 'three colour' in Spanish and relates to the tolerance folder used at Envases. It incorporates a maximum, minimum and standard production colour target.

this result displays a ΔE of over 4 from the previous measurement batch, it does not mean that the cans produced from that point on were out of tolerance. It may simply show an adjustment made by the press crew to bring the colour back into tolerance, as the press may have been previously operating at either the maximum or minimum acceptable limit. However, a ΔE of 4 would be clearly visible to the naked untrained eye.

The results gained for Lines 7 and 8 were taken for four designs, the Fcuk blue, Old Spice red, Toni and Guy red and Lynx black. The results for the Fcuk (for both lines) and Lynx show little to no variation over the measurement period, indicating consistent production. However, highlighted by the results is the colour difference between the standard (production target) and production itself. Although the variation is only of the magnitude ΔE 2, operating at this limit leaves no room for error, as any mistakes would cause production to be out of tolerance. Ideally, production should be run to match the standard, thus allowing any variations to be kept within tolerance. The consistency of the Old Spice and Toni and Guy reds display larger variation than that of the others. However, the variation (apart for one batch reading) is still within ΔE 2 and therefore would be within acceptable commercial limits.

Line 9 is dedicated to the production of Lynx. The results displayed show extremely consistent production throughout the measurement period with minimal colour variation. However, as highlighted from the results taken from Lines 7 and 8, there is the colour variation between the standard and production, which leaves little to no room for error. Line 9 is the newest of all the lines and the results also show it to be the most consistent.

The above results highlight the high consistency of the printing process, especially those for Lynx and Fcuk. However, as identified with the reds there are some areas that need to be addressed to maintain consistent quality across all designs and production lines. Also highlighted from the results is the difference displayed between the target colour and that produced.

3.2.3 Current Tolerance Limits

The standard tolerances set prior to the use of spectrophotometry were a very crude method of monitoring. For each design, several tolerance folders were created by visual assessment, incorporating an ideal standard, maximum and minimum colour and hence acceptable variation. These copies of the tolerance folder, known as the 'Triptico' (three colour) were then sent to the customer for acceptance prior to manufacture. The operator would then use these triptico's during production to monitor the current process performance and keep within the tolerance.

Although these tolerances folders are a very good and quick reference, they also have inherent problems, which have been highlighted by the work carried out. The first is variations between observers and illuminants, not only between factory and customer, but also between different operators. The second is that of creating a tolerance folder without knowing the capability of the process. This could lead to tolerances being set that are so tight they can never be maintained or are so wide as to compromise quality. Figures 3.10a-d display the variations between the maximum and minimum when compared to the standard for a selection of tripticos, component data can be seen in Appendix 4.

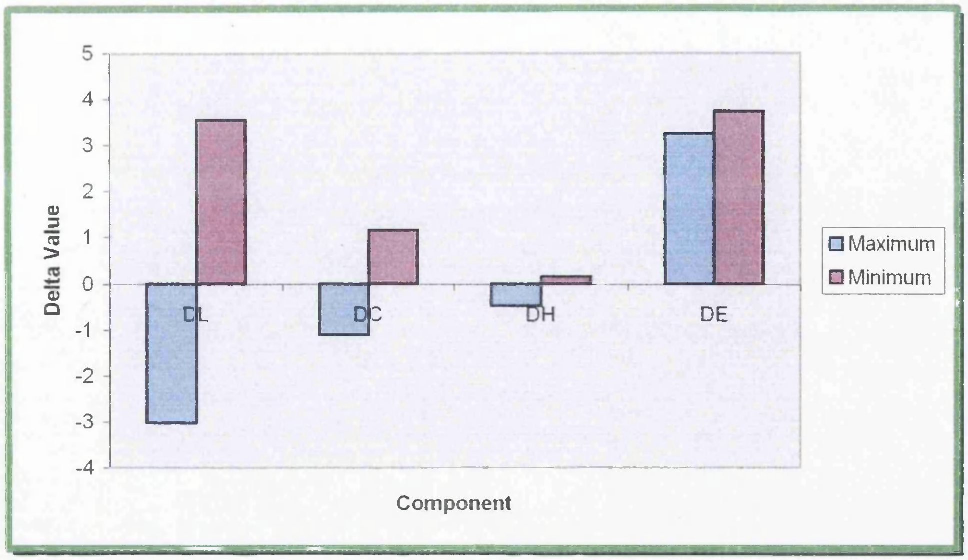


Figure 3.10a Green Triptico Data

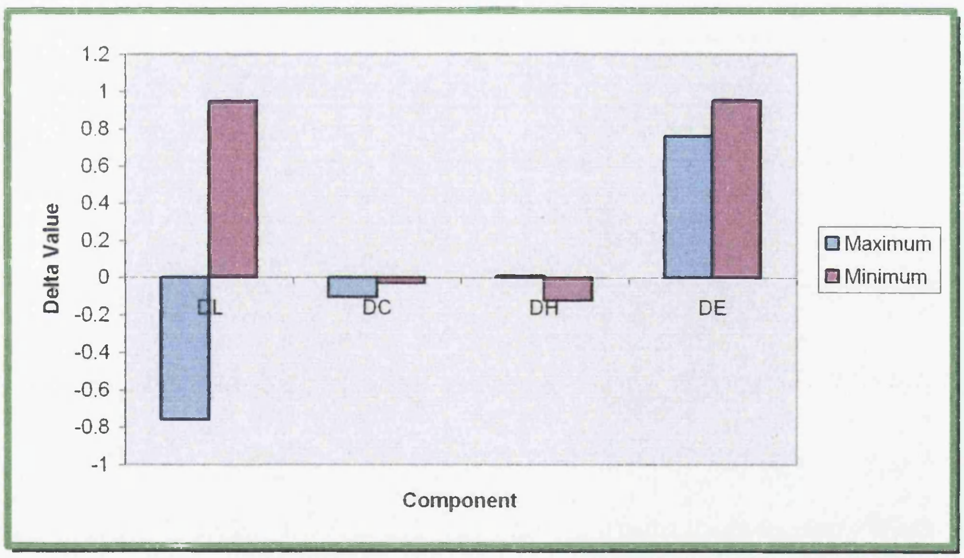


Figure 3.10b Red Triptico Data

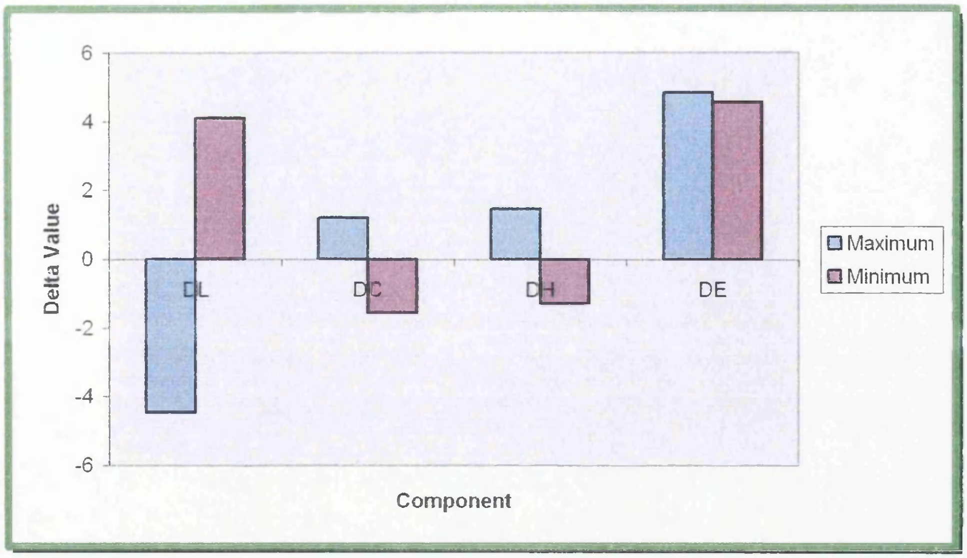


Figure 3.10c Blue Triptico Data

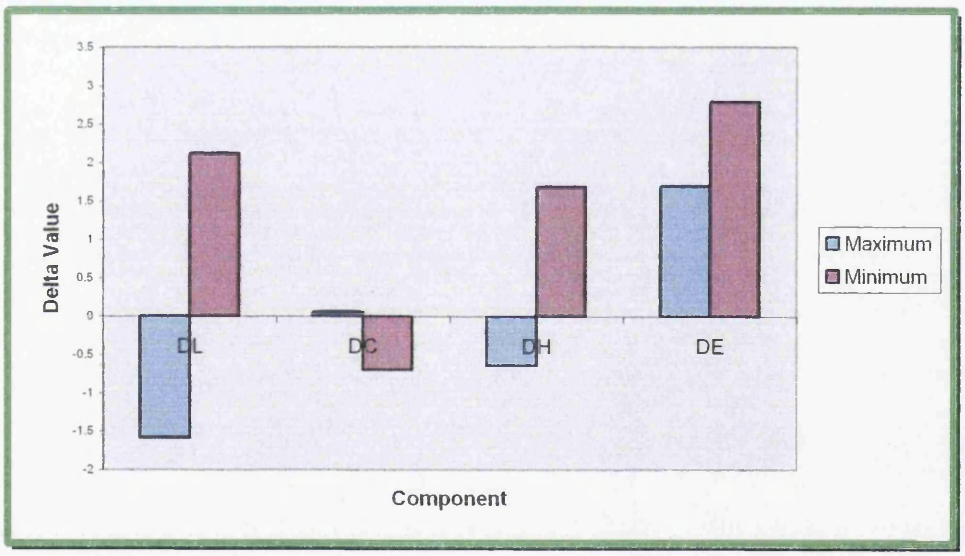


Figure 3.10d Yellow Triptico Data

Those tolerance limits displayed in Figure 3.10b are approximately $\Delta E \pm 1$. When comparing this to the results shown previously in Figures 3.3-3.9, it is evident that these tolerances are set too closely to be maintained across the whole of production. Figures 3.10a and 3.10c display colour differences of the magnitude $\Delta E \pm 4$, which when compared to the current process performance highlight that the tolerances have been set too wide and production could be maintained with tighter tolerances.

The above results have shown that the tolerances should be set to conform to the specific production capabilities and discussion with the customer. They have also highlighted that in the majority of cases, the L component of colour contributes more than the others in the calculation of the ΔE, unlike similar work has found [12].

3.3 Standardising the process

3.3.1 Ink film thickness

This part of the investigation was carried out to identify how colour varies with increasing ink film thickness. This could be used to identify the current ink usage, which could then be optimised for both consistency and quantity, which would ultimately be built into the formulation system. As shown in section 3.1, colour variations are observed throughout the print run, even though the ink formulation remains the same. It is, therefore, believed that the colour variation is due to the varying ink film thicknesses printed during the print run [24]. With this in mind it was decided to investigate this variation.

In four-colour work, the colour required is made up of varying amounts of cyan, magenta, yellow and black, and the colour will vary should the amount of any one of these inks change during the print run. When using non-process inks, the colour will only vary should the quantity of ink or ink film thickness increase or decrease over the print run.

There is a very fine line between too little ink, which will cause large colour variations, and too much ink, which would be seen as a waste. The reason behind this is that all inks at some thickness will saturate, meaning that the colour will not vary if any more ink is laid down. But if the ink film thickness is too thin, the colour variation will be dramatic if only a small amount more ink is laid down. An example can be seen below in Figure 3.11.

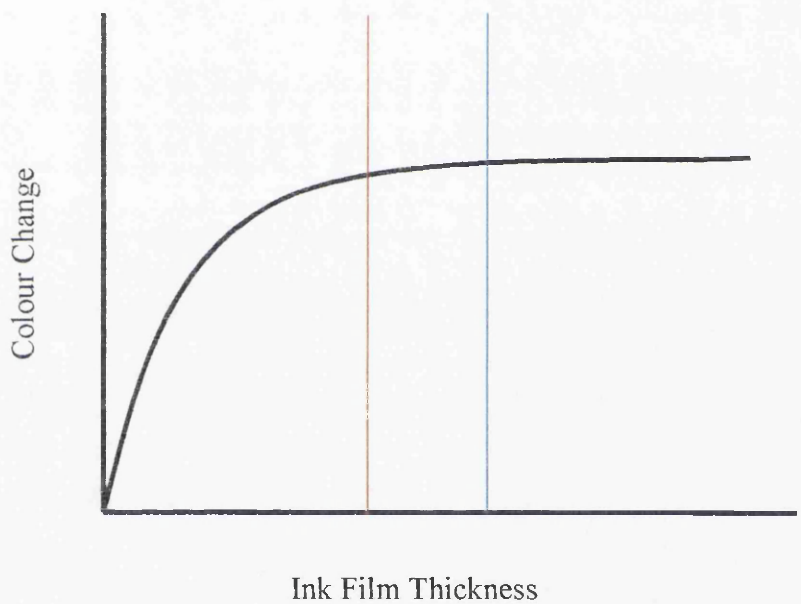


Figure 3.11 Schematic of Colour Variation with Ink Film Thickness

As can be seen in Figure 3.11, even a small drop in ink film thickness will cause a large variation in colour, particularly at the lower film thickness. The region between the red and blue line represents the optimum ink film thickness band, where colour variation is minimal and not too much ink is used. For thickness in excess of the blue line, the amount of ink used is excessive as it has little to no effect on the colour produced. An investigation was carried out using various coloured inks to identify the optimum ink film thickness required to minimise colour variation whilst maintaining acceptable ink usage. This was then compared with current production to identify any areas for improvement. The results of this can be seen in Figure 3.13.

Since ink film thickness is in the order of microns, its accurate measurement introduces a significant challenge and two techniques were explored. The first of these was to simply weigh the amount of ink transferred to the can. As the printed area is also known, the weight of ink per unit area can be calculated. Knowing the density of the ink then allows the thickness of ink to be calculated. The second technique used was to use white light interferometry [25], which gives a direct measure of the ink film thickness, see Appendix 1.

An initial experiment was carried out without the use of the adapted IGT printability tester. A detailed description can be seen in Appendix 2.

White base coat cans were used for the experiment and these were printed using Old Spice red ink. Thirteen different levels of ink were used, ranging from 0 up to 2ml being applied to the distribution rollers, which represents 0 to approximately 8micron being applied to the can. An average of three prints at each level was used to minimise the colour variation displayed in Figure 3.12.

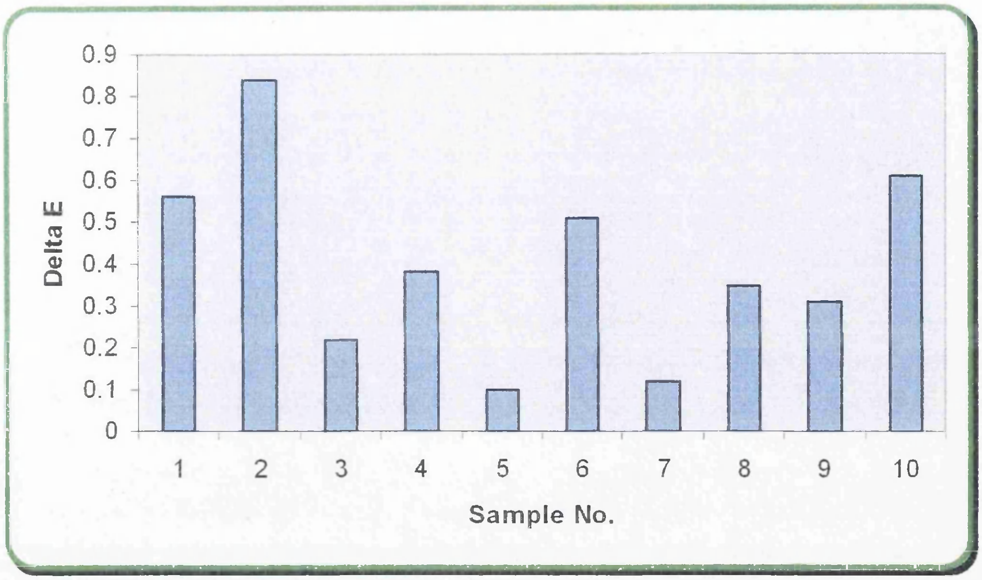


Figure 3.12 IGT Print Colour Variation

Figure 3.12 displays the variation in colour when measuring ten identically produced prints on the IGT printability tester, i.e. same ink quantity and type, and can. The ten samples were compared to a pre-produced can (standard) created in the same manner. The results show minimal ΔE variation between samples, the largest approximately 0.8, which is undetectable by the naked eye. However, as there is variation present and as previously mention an average of three prints will be used for subsequent experiments.

All the cans once printed were then dried on the production line ovens during normal production. Once the samples had been dried, they were then ready for colour measurement. Colour measurement was once again carried out using the spectrophotometer under standard operating conditions. Great care was taken during the colour measurement, as any fingerprints or contamination of the print would cause errors in the results due to the delicate nature of the unvarnished print. The results are shown in Figure 3.13 below.

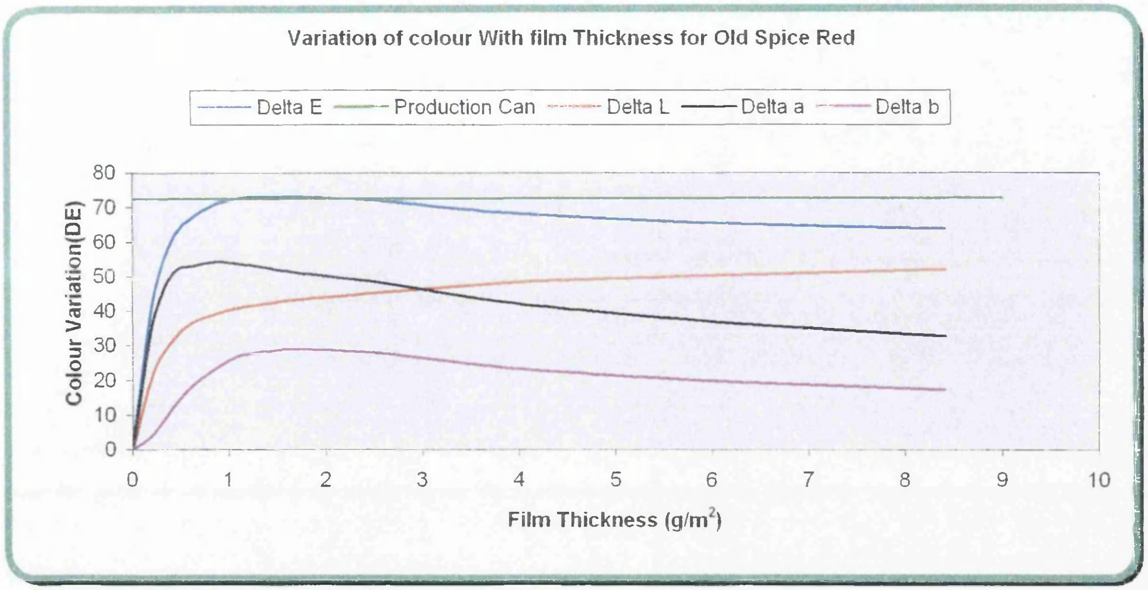


Figure 3.13. Variation of Colour with Ink Film Weight.

The above graph displays the results gained from examining the variation of colour with increasing ink film thickness. The graph not only displays the overall calculated colour difference but also the difference in the three components of colour. From the graph, it can be seen that at approximately $1g/m^2$ ink film weight, the ink has almost reached saturation, and from that point on, the change in colour compared to the film thickness is minimal. From approximately 2.5 g/m^2 onwards, the graph displays a reduction in the colour difference in comparison to the measure standard. The reason for this is that once the colour has reached saturation, the ink will tend towards black and therefore lose colour or Chroma, although the ink is still saturated.

At around 1.5 g/m^2, the result shows that not only has the ink reached saturation but the ink usage is also at an acceptable level. For all subsequent formulations, an ink film thickness of 1.5 g/m^2, which equates to 0.3ml applied to the IGT printability tester (as shown in Appendix 1) will be used.

3.4 Identification of Dominant Process Parameters

In order to control any process, it is vital that the process is fully understood. This requires breaking down the process into a number of components, thus highlighting those parameters that may have a dominant effect on the process performance. In doing this, the complexity of the process can be appreciated and a scientific understanding is developed.

In considering the full range of process parameters, it was found that there are a considerable number that can affect print quality. However, many of these parameters are either likely to have a minimal effect, or more importantly cannot be controlled practically in either a laboratory or production environment. Figure 3.14 displays the numerous printing process parameters that may affect print colour or quality, displayed as a fish-bone diagram [26]. These have been grouped according to environment, substrate, ink, plates, operator, press and over varnish.

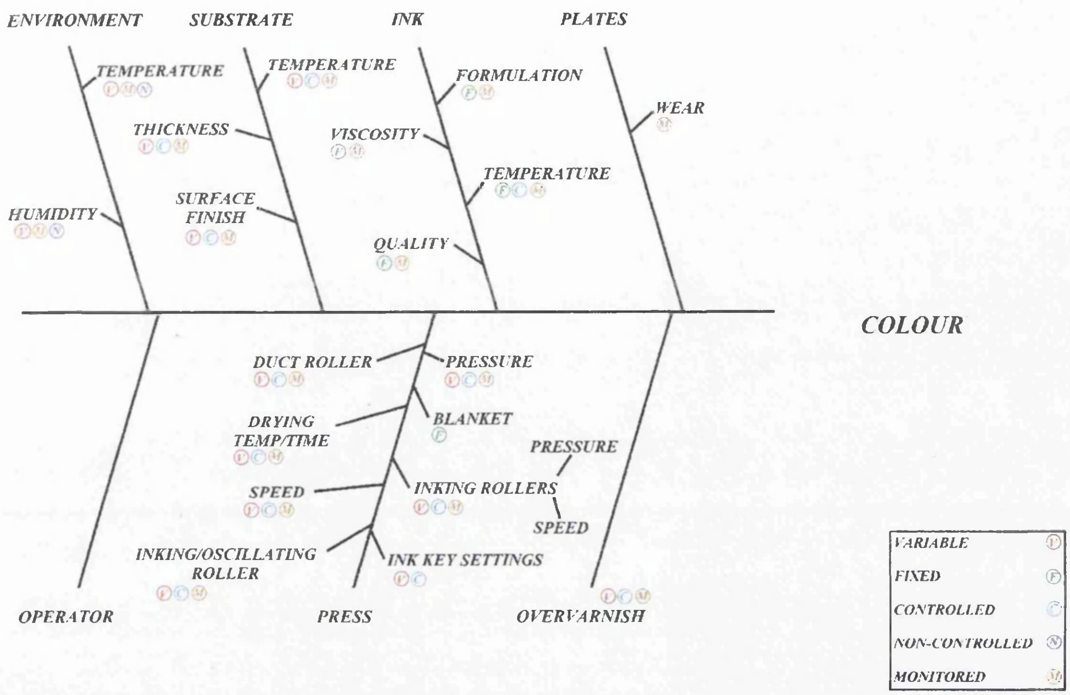


Figure 3.14 Cause and Effect diagram

The key displayed in the bottom right of Figure 3.14 highlights the status of each parameter during production. The variable and fixed icons indicate whether the parameter can be changed during production. The controlled and non-controlled icons specify whether the parameter variation can be controlled and maintained by press operations. Finally, the monitored icon indicates that the parameter variation can be recorded, by some means, during production.

As can be seen in Figure 3.14, there are still a large number of parameters under each group heading that may affect print colour or quality. Environment covers the operating surroundings such as the factory temperature and humidity. Substrate details the surface on which the print is created, in this case an aerosol can. Under the heading, ink, ink rheology is highlighted through the ink temperature and viscosity. Formulation represents procedural processes required to maintain consistency and quality represents colour variations that maybe present in the incoming ink from the supplier. Plates characterise the printing form used, and if its degradation during the print run can affect colour. Operator describes the press crew and their ability to effect changes during production. Press encompasses the printing press itself as described in Chapter 1. Over vanish covers variations, which occur to the protective layer applied after the print and the effect that may have on the colour.

For reasons mentioned above some of these groups were not investigated. Those parameters listed under environment were not explored due to either the extreme cost of incorporating an air-conditioning system into the factory or the impracticality of moving the press into a controlled environment. Other factors such as plate wear are inevitable but minimal during a production run and were therefore eliminated from the scope of this project. The parameters investigated were those that would not interrupt or hinder production, as well as those that could be replicated in a laboratory environment.

In order to quantify the effect of these parameters, an experimental investigation must be carried out to assess the impact of each parameter and highlight any interactions that may occur. Before this is achieved, the working limits of each of these parameters must be identified, along with methods of monitoring their variations during normal operation.

The selection of parameters used during this experimental investigation was primarily achieved with the use of operator experience, and those parameters that the operator has the ability to vary. The idea being the number of parameters that the operator can vary is reduced, thus limiting the effect of the operator, as well as highlighting the impact of these variations

3.5 Effect of Process Parameters on Colour

A series of investigations were carried out in order to identify the effect of some of the parameters displayed in Figure 3.14. The results from this are presented in detail in the following subsections.

3.5.1 Substrate

3.5.1.1 Temperature

Several preliminary tests were carried out to identify the extent to which the substrate temperature varied during a print run in order to find out if the temperature variation was sufficient to cause ink film thickness changes.

The temperature measurements were taken at 10-minute intervals during normal press operation, with the use of an infrared thermometer [27]. The average temperature of five clear base coated cans was measured just before they entered the printing unit, thus allowing any can to can variation to be identified. The results are presented in Figure 3.15.

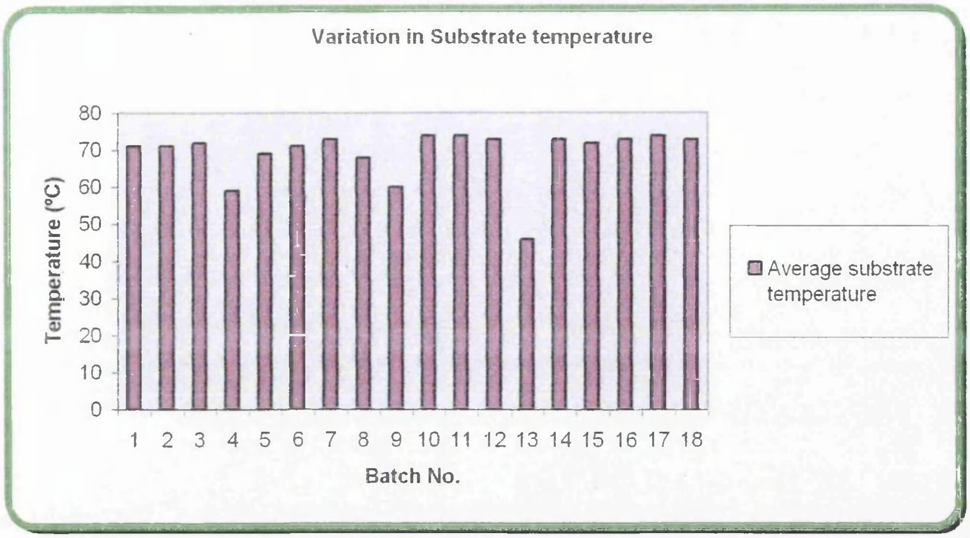


Figure 3.15 Variation in Substrate Temperature

From the measurements taken it was highlighted that the variation from can to can was approximately ±2°C, which is sufficiently small so as not to cause any problems during the print run since the colour variation remains within acceptable limits. However, there was a variation in temperature across the whole set of readings of 28°C as seen in Figure 3.15, which may cause printability problems.

These large temperature variations only occurred when the press had stopped for an extended period of time, thus allowing the cans time to cool between the oven outlet and the printing press. In order to test the effect of this temperature change on ink transfer, ten cans were removed from the press before being printed and allowed to cool to approximately room temperature (28°C).

In order to measure the colour variation from the cold to the hot cans, the ten cold cans were marked and placed back onto the production line to allow them to be printed. The printed cold cans were then removed from the line along with the next

20 cans, which had not been allow to cool, thus allowing a comparison with normal production. The variation in colour between the two sets could then be measured, the results of which can be seen in Figure 3.16.

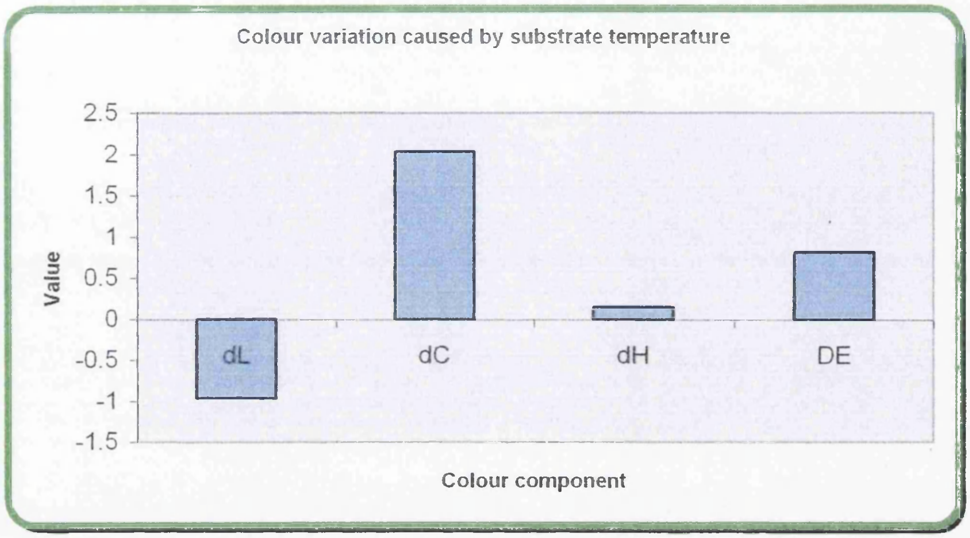


Figure 3.16 Colour variation due to Substrate Temperature

The results displayed above highlight the difference in colour when printing on to hot or cold cans. Although the variation is minimal and would not cause any critical colour variation, there is a small variation in the lightness and Chroma values between the two sets. The cold cans displayed higher values for lightness and lower values for the Chroma (Hue values are almost identical due to the same colour ink). This would suggest a reduction in the amount of ink printed onto the cold cans, or a patchier print, thus allowing the colour of the basecoat to affect the printed colour.

This investigation has highlighted that can temperature affects the colour of the printed cans. The colour difference is not large enough to cause a major quality issue, since it fell well within acceptable tolerance limits.

3.5.1.2 Thickness

The thickness of the substrate, in this case the can wall, varies depending on the dimensions and mechanical requirements of the cans i.e. pressurisation induced stress. This variation in thickness will obviously have some effect on the pressure between the can and the printing blanket, as the pressure on the press is set by the distance between the printing head and mandrels. However this distance can be changed, allowing the various can diameters and thickness to be printed.

There is a natural variation in the thickness of similar cans due to the extrusion process. Generally the wall thickness is in the region of $0.6\text{mm} \pm 0.01\text{mm}$. As this variation is inherent to the extrusion process, it cannot be eliminated without a detailed investigation into that process, which is beyond the scope of this investigation. The variation in can thickness will therefore be incorporated into the results from this investigation as a noise effect and will not be explored explicitly.

3.5.1.3 Surface Finish

As mentioned in Chapter two, after the cans have been formed by the extrusion process and cut to size, they are then brushed to give a suitable finish. Not only does this brushing give the can a highly reflective finish, but it also gives it a texture. Depending on the type of brush used, the surface texture will also vary causing a difference in the perceived colour due to the light reflecting differently off the can surface. This variation will only be caused when printing onto a transparent basecoat, due to the fact that a white basecoat fills and hides the brushed finish.

In order to identify whether or not this brushing effect would alter the perceived colour, a simple experiment was carried out. Various cans, which had been brushed with different grit brushes were removed from the different lines. There were three types in total. The surface finish of the various cans was measured using the white light interferometer to identify any variations in the surface roughness from can sets, as well as can to can. The collected cans were then coated using a clear basecoat on the same production line in order to maintain consistency and then printed at the same film thickness (production levels) with the same ink (transparent red) using the IGT printability machine. The various cans were then measured using the spectrophotometer, compared to a pre-prepared standard, and any correlations between brush finish and colour were highlighted, the results of which can be seen in Figure 3.17.

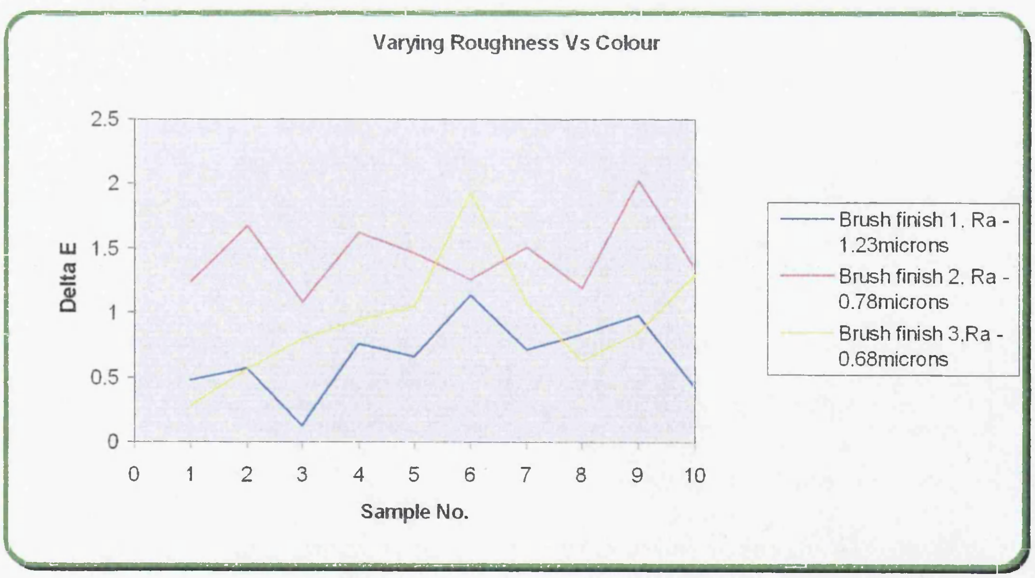


Figure 3.17 Varying roughness Vs Colour

The results in Figure 3.17 show that under production conditions there is no obvious correlation between the surface roughness produced from brushing and the perceived colour after printing. The main result that can be drawn from this is that substrate roughness has little impact on perceived colour. With regard to production, it implies that initial brushing is not an important consideration

3.5.2 Basecoat

Several investigations were carried out to highlight the effect of basecoat. The first of these was to highlight normal thickness variation during production, which included three separate experiments as described in section 3.5.2.1. The second investigation was to highlight the effect of any thickness variation on both basecoat and final print colour.

3.5.2.1 Basecoat thickness variation

This investigation was carried out to help identify the current performance of the base coating machine. The aim was to highlight any major variations during production of the thickness of the basecoat, and any problems this may have on the printing process.

The first experiment carried out required the measurement of basecoat thickness of sixty cans, removed from the production line in sequence. This was then varied for the second experiment to identify how missing cans (a common problem during production) affected the basecoat thickness. The cans were put through the base coater in a constant stream, but after every 10 cans, a number of cans (from 1 to 8) were removed. The cans were then measured using a Fischer Isoscope thickness gauge [28] in three places around the can's circumference and an average taken. The Isoscope was chosen over the white light interferometer due to the speed of measurement and the thickness of the basecoat. Both these experiments were repeated for the third experiment where an oscillating roller was introduced in contact with the coating roller to identify any improvement this had on coating consistency.

This investigation was carried out using a clear basecoat due to production scheduling. The thickness of the clear basecoat is less than that of the white basecoat, but for the purposes of a comparative trial, using a clear basecoat is still appropriate.

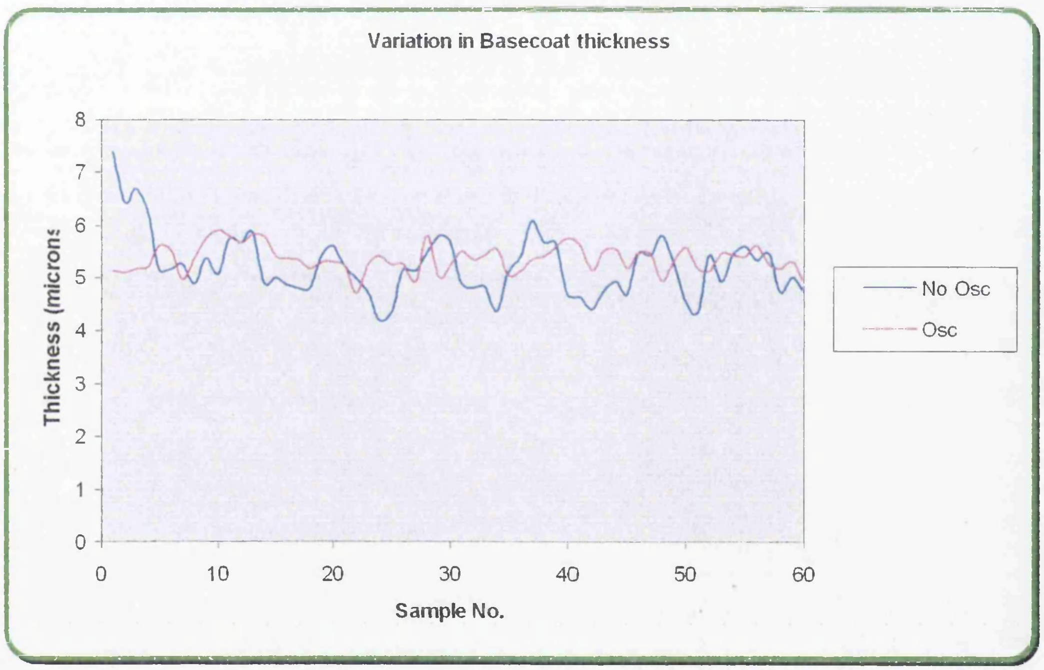


Figure 3.18 Variation in Basecoat Thickness

The results displayed in Figure 3.18 show the natural variation in basecoat thickness for sixty cans during continuous production. The results displayed for normal machine operation (no oscillating roller) highlight a natural frequency in thickness that occurs at about every ten cans. The thickness varied by approximately 2 micron during the trial. This is a significant change when the average thickness is approximately 5 micron. The reason for the frequency of variation is most likely to be due to the build-up of ink in the coating nip. The base coater uses a simple coating method and unlike the printing machine uses very few distribution rollers as shown in Figure 1.3a.

With the oscillating roller operating, as seen from the results, this frequency of variation is eliminated, and the size of variation is reduced to approximately 1 micron. The reason behind this is that the oscillating roller not only distributes the ink better across the rollers, but the introduction of a second nip operates as a further metering device. It is obvious from the results that the oscillating roller improves basecoat consistency by reducing variation.

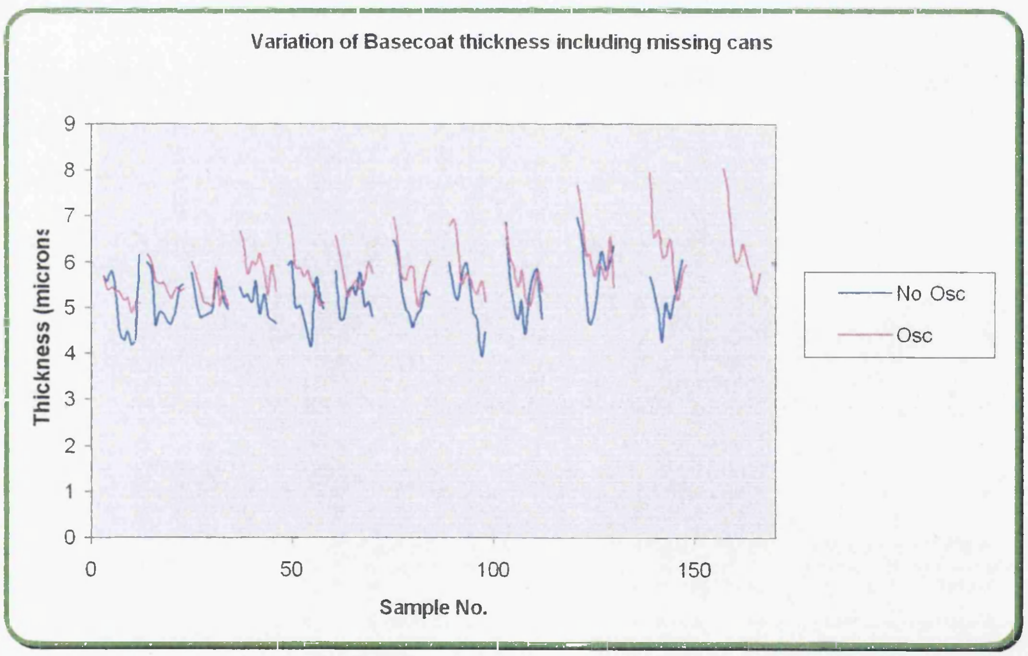


Figure 3.19 Affect of Missing Cans on Basecoat Thickness

The results displayed above highlight the effect of missing cans on basecoat thickness. As with the previous trial, the results were taken with and without an oscillating roller fitted to the base coater. The results from both trials show a distinct increase in basecoat thickness after the missing cans. The reason for this is that as the delivery of the basecoat is continuous, if the basecoat is not removed from the system, it will build up, leading to a greater thickness being printed on subsequent cans until the amount of basecoat in the system stabilises and returns to a normal level. As expected, the build-up of fluid in the system depends on the number of missing cans, the larger the number of missing cans, the larger the film thickness printed on the next can into the system. Also apparent from the results is the number of cans required for the system to re-stabilise, which in this case is approximately ten consecutive prints. One unexpected result is that for the oscillating roller attached. Unlike the previous results, with the oscillating roller attached, the variation before and after the missing can gap is far larger than that of the normal operation. The likely reason for this is the nip of the oscillating roller acting as a second reservoir, therefore allowing more basecoat to be stored up in the system.

The results from this experiment indicate the variation in basecoat thickness is sufficiently large to warrant an investigation into the effect of the basecoat variation on colour. Also identified is the compromise of fitting an oscillating roller to the system. Although it does reduce variation during continuous production, missing cans are a common occurrence during production and this leads to larger film thickness variation when the oscillating roller is fitted. The problems associated with this latter mechanism may outweigh the other benefit.

3.5.2.2 Basecoat colour variation

This investigation was undertaken with the purpose of identifying the inherent colour variation within the base coating procedure. As the clear basecoat has no colour, the surface finish, after brushing, of the aerosol can causes any colour variation. This was discussed previously in this chapter and was shown to be negligible. However, the white and coloured basecoats will vary in colour due to natural variations in the base coater. In order to identify the extent of this colour variation and the effect on the final print colour, forty-two cans were measured prior to and after printing. Forty-two cans were used due to limitations caused by sample stock and production scheduling.

The cans were removed in sequence from the production line during an uninterrupted period of manufacture. These cans were then numbered and colour measurements were taken at 4 points around the can's circumference at the mid height in order to gain an average colour for each can, the results of which can be seen in Figure 3.20. Once this had been achieved, each can was printed at the same film weight with the same ink using the IGT printability tester. The cans were then put through the production line ovens to dry without an over varnish being applied. Once the cans were finished, they were re-measured in order to identify any correlation between the colour variations, the results of which can also be seen in Figure 3.20.

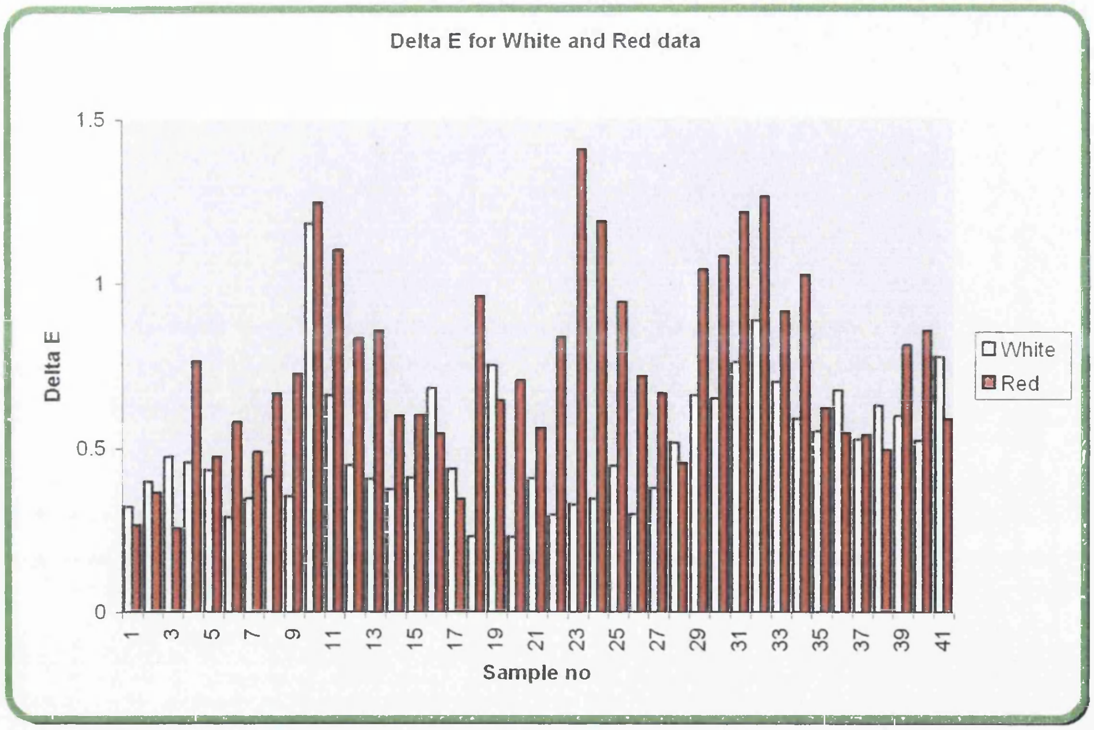


Figure 3.20 Colour variation due to basecoat variation

From the above results, it can be seen that the colour variation in the white basecoat never exceeded a ΔE value of 1, except on one occasion. As previously mentioned a ΔE of this magnitude can only just be perceived by the human eye. This shows that although there is variation in the thickness of the basecoat, the colour variation is minimal, indicating that the basecoat coverage is thick enough for the colour to reach saturation.

The results display a higher variation in the red ink, although the maximum variation (ΔE) is still less than 1.5. It can also be highlighted that there is no correlation between the colour of the basecoat and that of the printed red ink. This would once again indicate that the red has been printed at a suitable level in order to attain saturation and therefore eliminates the effect of the basecoat.

3.5.3 Ink

3.5.3.1 Formulation

Ink formulation was investigated at several stages, the first of which was to identify ways in which colour variation could be minimised throughout production (discussed in Chapter 4), and the second was to establish simple methods to ensure consistency through the formulation process.

a) Ink formulation methods

Colour consistency from batch to batch is as important as throughout the run. It was therefore important to identify any areas of inconsistency throughout the formulation process. The first area of inconsistency to be identified was that of the initial colour formulation. At this stage of the project, this was carried out in a laboratory environment by the colour matcher. When colour matching, only a small amount of ink is mixed at any one time, for example a 5% of that mixed for production. However, the weighing scales used for this procedure were the same as those used for production, having a measurement resolution of 0.1grams. On regular occasions, the quantity of an ink required in the formulation will be typically 0.1grams and the amount weighed added could be from 0.05 to 0.14grams equating to a large error. This leads to inconsistencies and colour problems during production. To overcome this issue, scales measuring 0.01grams were required for formulation. In order to ensure consistency between formulated ink and that mixed on line, a new quality procedure, pre-checking the ink before production, was introduced. This involved a simple draw down test, using a K-bar, to check the mixed ink matched the standard.

The procedural changes described above highlighted the need for a formal colour matching procedure. The changes made were essential for the successful implementation of a formulation system and this will be described in Chapter 4.

b) Formulation thickness

As previously detailed in this chapter, at a certain thickness level, an ink will become saturated. In order to maintain colour consistency, it is important that the formulated ink is produced to print at the correct thickness. With the use of the formulation system, it is possible to maintain ink film thickness across all formulations, thus maintaining consistency throughout production. The ink film thickness adopted for formulation was derived from the results shown in Chapter 4.

3.5.3.2 Temperature

In order to monitor the temperature of the ink throughout the production run, a data collection system was required. This allows automatic identification of any major temperature fluctuations, which in turn may impact on colour variations.

Thermocouples (Type-T) were used to measure the temperature at several locations on the press, including several of the inkwells. The thermocouples themselves were held submerged in the ink by bulldog clips, thus allowing continual measurement of the ink temperature.

The thermocouples were connected to a Schlumberger Technologies 'IMP' (Isolated Measurement Pod) analogue data collection module, which in-turn was connected to a PC running a custom written Qbasic program.

The custom written program allowed the user to specify polling intervals and measurement duration. For the purpose of this investigation, the thermocouples were polled every 30seconds. This gives a suitable frequency of temperature readings to monitor the long-term stability of the printing process.

Measurement was carried out on several of the lines at various times during the day, some overnight, thus identifying any temperature variation due to the factory environment. From the initial results shown in Figure 3.21, it was identified that the cooling system connected to the printing press was not operational.

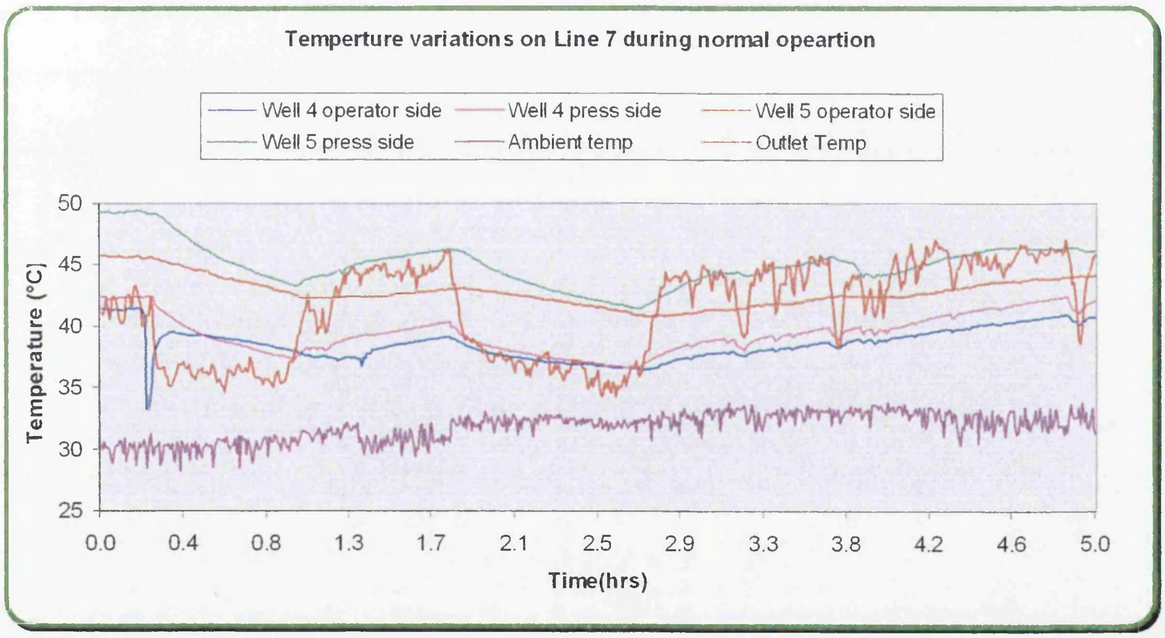


Figure 3.21 Ink Temperature without Cooling System

The results above indicate the normal temperature fluctuations found on Line 7 during normal production. These were similar to those found on the other production lines. It highlights the variation found, not only during a print run but also the variations found in different areas of the press. The outlet temperature gives an indication of the press status, running or stopped. This is due to its locality to the oven outlet, which, when the line is running, allows a draught from the ovens to escape past the thermocouple. This temperature reading also coincides with the reduction or increase in ink temperature as it is allowed to cool during press stoppages. The ambient air temperature shows only a slight variation of approximately ± 3°C during the production run.

The first point to be highlighted is the high operational temperature of the ink. The recommended temperature given by the manufacture is between 32-35°C, about 10°C lower than that displayed above. Operating at this high temperature will influence the rheology of the ink, which in turn will increase the risk of the phenomenon known as misting[2]. The variation in temperature across the data set is also relatively high. The temperature of the ink in the inkwells varies by approximately 7°C during the production run. This could cause sufficiently large variations in the ink rheology to produce critical colour variation during a print run.

Other temperature variations highlighted from these results are, the temperature variations between the inkwells and the variation between the press and operator sides. The simple reason for the temperature variation between the inkwells is that heat rises, and therefore the inkwells at the top of the press will be hotter than those at the bottom, as shown in the results. The variation across the wells is caused by the fact that the operator side is open to the factory, whereas the press side is

[2] Fine droplets of ink created at the point of nip separation, as the ink is pulled apart by the two rollers.

located by the mechanical parts of the press, which will obviously be hotter, thus making the ink hotter.

To eliminate the variation in ink temperature throughout the production run and bring the ink within recommended operating temperature limits, the cooling system was utilised. The cooling system comprises a closed loop water system. Water, maintained at a known temperature, is passed through the duct roller at a constant flow rate. The returning water is then cooled and once again passed through the duct roller, see Figure 1.3, allowing the system to be maintained at a constant temperature. Although the water used for the cooling system is maintained at a constant temperature (28°C), the temperature of the ink is unknown. Therefore the data logging system was used to monitor the ink temperature whilst both the production line and the cooling system were in operation. The results can be seen in Figure 3.22.

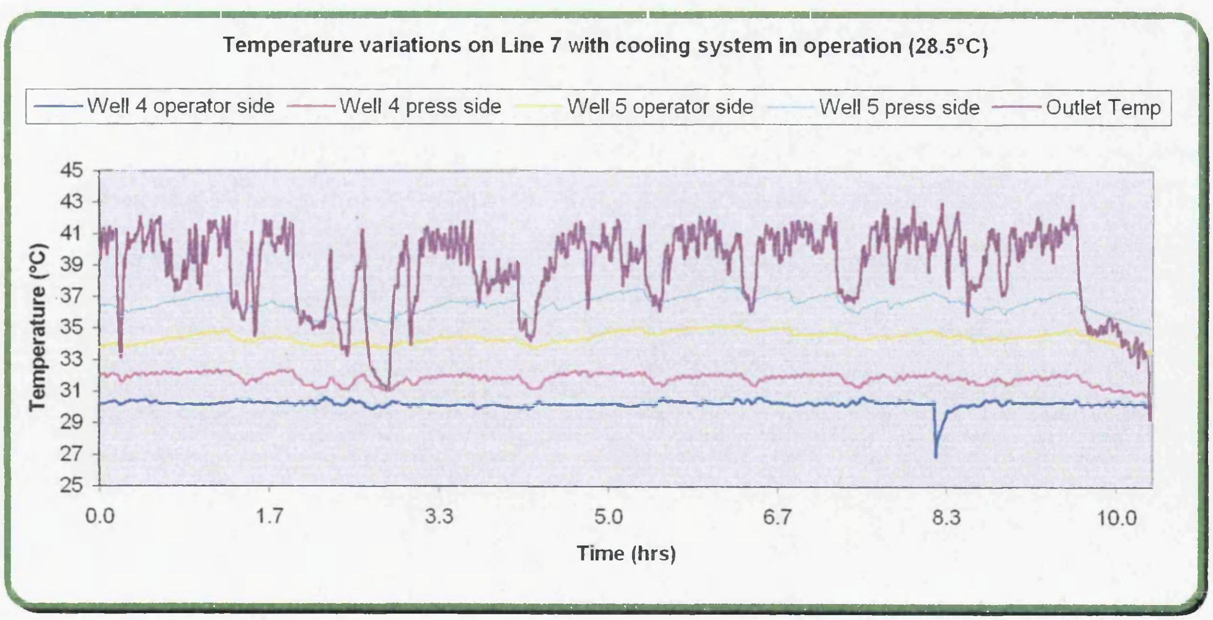


Figure 3.22 Ink Temperature with Cooling System

The results above display the temperature of the ink during normal production with the cooling system in operation. The water within the cooling system was set and maintained at 28.5°C. This held the ink temperature much closer to the recommended value. However, the variation in inkwell temperatures (top to bottom) could not be eliminated. This can only be achieved if a separate cooling system was used for each supply train.

In contrast to the previous results, Figure 3.21, the variation in ink temperature throughout the production run, has been reduced to approximately ±1°C, which is almost negligible. There is one instance when the temperature on well 4 operator side drops sharply by 4°C, before recovering back to a normal temperature. The only reasonable explanation for this is that the ink in the ink well almost ran out. Whereas ink is normally added in small amounts throughout the production to minimise this temperature jump, in this instance a large amount of ink would have been added to the well at one go, accounting for the sharp reduction and a later gradual rise in temperature. The variation between press and operator side is still apparent, but this is inevitable due to the mechanical design of the press. With the cooling system in operation, the ink temperatures are maintained at a level recommended by the manufacturer. As shown previously it does not cause quality problems during production, therefore rendering an investigation into the effect of ink temperature on colour variation unnecessary.

3.5.3.3 Viscosity

The inks used at Envases have been shown to be Non-Newtonian and pseudoplastic/shear thinning [4]. Ink viscosity has been highlighted as one of the direct causes of colour variation [7]. However, when related to the printing process in question, its effect can be eliminated for the following reasons.

Firstly, ink viscosity is directly related to temperature, generally as temperature is increased, the viscosity of the ink will decrease. As previously shown, the temperature of the ink during production can be maintained to within ±1°C, therefore rendering any effect on viscosity minimal.

Secondly, viscosity is also directly related to the shear rate. As an ink is worked, its viscosity will general reduce until it reaches an equilibrium and becomes sufficiently sheared. This is not only related to the shearing time, but also the shear speed, hence rate. With the printing process in question, the ink is sufficiently worked by the distribution rollers so as to reach the point of equilibrium, and the variation in production speed throughout a run, and hence shear rate, is insignificant.

3.5.4 Operator

The press operator ensures the smooth and continuous running of the production line. However, not every operator is the same and not only will they perceive colour differently, but many have various methods of running the press to achieve consistent production. The only way to eliminate this variable is to incorporate technology removing the operator from within the control loop.

The introduction of spectrophotometry removes the variation in colour perception between the operators, due to reasons discussed in Chapter 2. This can be aided further with the use of a formulation system, minimising any issues associated with colour matching. However, complete automation of the press requires leading edge technology and substantial investment. Process automation was not within the scope of this work. It is possible to incorporate training methods, which not only standardised the operating procedure, but also highlight the results shown by this project. This, in turn, would give greater understanding of the process, highlighting typical variations, why they occur and actions required to limit their effect.

3.5.5 Press

As can be seen from Figure 3.14, there are a large number of parameters under the heading of press that can affect the colour during production. The investigation of these parameters is not only complicated by the fact many of these parameters interact with one another, but also monitoring of many of the parameters will require modernisation and full instrumentation of the press. Even if the press were instrumented to allow monitoring, a detailed investigation into the effect of these parameters would require valuable production time. This was not justified at this stage since Envases already prints within acceptable customer set tolerances.

Through observation of press practices, it was identified that once the press had been set-up and stable production had been achieved, many of the parameters listed were not varied during production and the press operated within its own natural variation. On the rare occasions changes were made during production, the operator called upon his/her experience to make suitable changes allowing production to be brought back within tolerance.

It was also observed that many of the parameters could not be varied easily on the production press. These include inking roller pressure and blanket.

Further investigation into the operation of the press [29], identified that many of the listed parameters are coupled. For example, if the press speed varied during production, the duct roller, inking roller speed, inking/oscillating roller would vary automatically to compensate for the changes. Drying time would also vary depending on the press speed. However, changes to the oscillating roller can also be made manually by the operator during production to increase or decrease the amount of ink fed into the system. This along with the ability to vary the ink key settings and print pressure are the main parameters used by the operator to maintain print consistency. Implementation of suitable instrumentation, which would allow the investigation into the effect of varying ink keys, print pressure and the oscillating roller was beyond the time scale/budget of this project. It must also be noted that the drying temperature had little to no variation from print run to print run, as well as during a print run and was therefore eliminated.

3.5.6 Over-varnish

Over-varnish is applied to the can in order to protect the delicate print from subsequent scratch damage. The application of over-varnish is carried out using a coating machine identical to that used to apply the basecoat. As previously shown in this Chapter an investigation into the variation in basecoat thickness highlighted significant differences through production. It was therefore decided to carry out an investigation to highlight the effect of over-varnish on colour.

A short printing trial was used in order to analyse the effect of over-varnish on the print in order to highlight any major colour variations caused. The samples used for this investigation were those of the Old Spice design. Twelve cans were taken from the press before over-varnishing and measured using the spectrophotometer to obtain an average colour. Once all the cans had been measured and labelled, they were reintroduced to the press in order to apply the over-varnish. The over-varnish applied, was that of the standard clear varnish used for the majority of can designs. Other varnishes such as matt and semi-matt are also used for selected designs. Once the cans had been over-varnished and dried they were re-measured and compared to the unvarnished samples as shown in Figure 3.23.

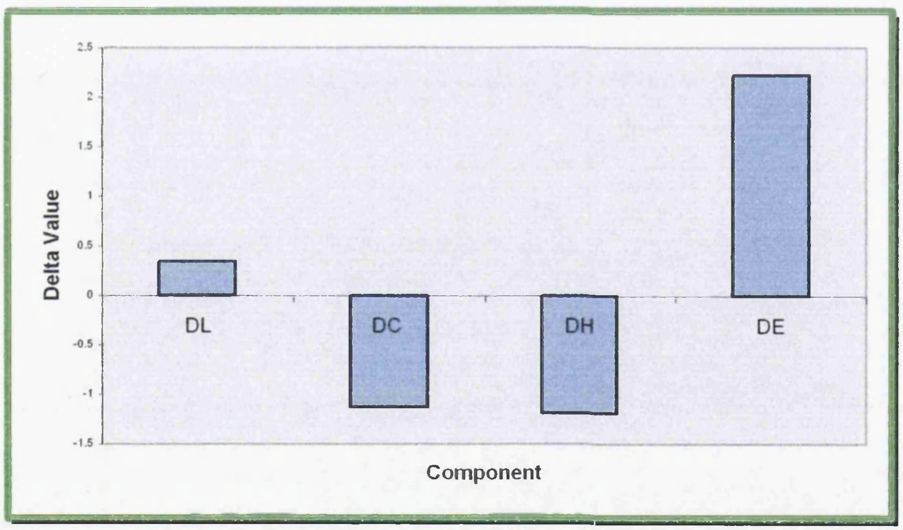


Figure 3.23 Colour variation due to over varnish

The results above show the variation in colour due to the over-varnish with the unvarnished cans taken as the standard. They results highlight a significant colour difference, with the variation in the hue component indicating the colour itself has changed. This variation in colour could either be caused by a slight pigmentation of the over varnish or light refraction/second surface reflection issues when the varnish is applied. A recommendation for a detailed investigation into identifying the root cause of this difference is stated in Chapter 5. The variation shown by the results, although significant, is not an issue during production, due to the fact that any cans produced without over-varnish would be easily identified and either discarded or reworked in order to apply the over-varnish. However, it has highlighted the care required when producing colour matches during formulation. Although the formulation would match without over-varnish, with the varnish applied, the colour could well be different and therefore not acceptable.

3.6 Closure

This chapter has highlighted the current performance of the process and the factors, which affect that performance. As many factors as possible were investigated to indicate the effected they have on production and to identify any causes for concern, the results of which are displayed. Solutions have also been investigated and discussed in order reduce the variation in colour during production.

CHAPTER 4
COLOUR MATCHING

4.1 Introduction

The purpose of this chapter is to investigate the use of colorimetry for the production of a process specific colour formulation system. This involves the creation of a database, enabling the application of the formulation system to prepare ink on a right first time basis. Also detailed within the chapter are the testing and evaluation of the system. Background information concerning the general details of a formulation system has been set out in Chapter 2.

In order to create a system to adequately formulate colour from a target, three essential components are required, a measuring device, a colour database and formulation software.

The measuring device is typically a spectrophotometer, similar to the one described in Chapter 3 and the database is a collection of typical base inks used for formulation as described later in this Chapter. The formulation software is used to process the supplied information from the spectrophotometer, which in turn creates a suitable colour match using the ink database. Several formulation software packages are available from various manufacturers', The GretagMacBeth ProPallete software was implemented and used during this project. These software packages implement the Kubelka-Munk theory as described in Chapter 2 to perform the necessary calculations required for colour matching. Although GretagMacBeth provide colour matching software, it was found that they have no experience of application in can decoration. Therefore the work in this part of the project presented a number of challenges that were over come to establish a successful result.

As described in Chapter 2, by using the spectral reflectance data and the Kubelka-Munk theory, it is possible to calculate the absorption and scattering coefficients for semi transparent inks. These can then be used to calculate the combined effect when two or more inks are mixed in varying quantities at a pre-specified thickness. By using these principles, the formulation software is able to match to a measured colour target at a set ink film thickness using a combination of inks stored in the database on a 'first-time' basis.

The number of sample colours used for the database will increase the effectiveness of the software to produce not only more colours, but also more alternative formulations for the same colour. This gives the colour matcher the advantage of using preferred inks.

4.2 Formulation system

In order to create a formulation system, a database is required to 'teach' the system about the specific inks and process requirements, thus giving the required information for optimum performance. A database is simply a set of accurate calibration samples produced at a known ink film thickness. Each colorant used for formulation requires a number of samples to be produced at various concentration levels. This is achieved by adding a varying amount of resin, in this case transparent white, to the colorant giving the samples either a strong or weak colour. For example, one sample could be produced with 25% colorant and 75% resin. All samples must be produced at the same ink film thickness on black and white cards, known as Leneta cards. The purpose of the contrasting black and white is to allow the system to identify whether the print is opaque or transparent and therefore determine the values of K and S for that colorant, as described in Chapter 2. A complete sample set should include colorant levels of 0% and 100% with any number of suitable combinations between (enough to fully describe the colour), the greater the number of samples the greater the accuracy of the database and therefore subsequent formulations.

Once the database samples have been produced, they can be measured using a spectrophotometer and entered into the software, giving each sample a signature described by its reflection curve. The reflection curves created for each colorant should give a detailed description for each colour. The reflectance data is used to plot the calculated absorption and scattering coefficients at set wavelength intervals for each concentration level. The absorption and scattering data gathered from the samples can then be used by the formulation software, by way of interpolation algorithms, to produce a suitable formulation to match the target sample.

As mentioned above, the formulation system requires the production of samples at a known and constant film thickness. This gives the system a distinct advantage over traditional methods of colour formulation, in that ink film thickness can be standardised. All formulations can be produced at an optimum ink film thickness, improving colour consistency and reducing waste. In order to accomplish a known ink film thickness a calibrated mini press (see Appendix 1), is required, allowing samples to be printed prior to full-scale production.

4.2.1 Database Sample Creation

As previously mentioned, in order to create samples, black and white metallic Leneta cards (Leneta Metopac Panels (Form T12G)) were used as shown in Figure

4.1. To be able to print onto these Leneta cards, the IGT printability tester had to be modified to allow printing onto a flat surface, made possible by reattaching the original printing components. Once the original components had been fitted, the database could be created. This was achieved in several stages as described below.

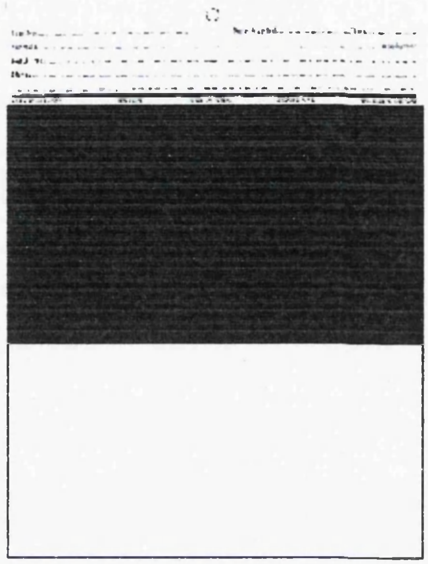


Figure 4.1 Leneta Metopac Panel

4.2.1.1 Sample ink film thickness

The first step in the production of the database is the determination of a suitable and realistic film thickness. As previously shown, in Chapter 3, the production film weight had been standardised at 1.5 g/m^2 (0.3ml using the IGT screw micrometer). It was therefore important to produce the database samples at the same or similar thickness and maintain this accuracy throughout all the database samples. In order to achieve this, the same technique used to identify the thickness transferred to the can was employed.

By a process of trial and error, varying amounts of ink were used by applying ink to the IGT with the use of the micrometer pipette. The panels were then weighed to identify the ink transfer. This was continued until a suitable weight of ink had been transferred in order to give an ink film weight of $1.5g/m^2$. The results showed that at 0.25ml of ink applied to the IGT, an ink film weight of $1.5g/m^2$ was achieved.

Samples were then produced for several of the colorants, measured and entered into the software. The results gained for each sample proved to be too variable, which in turn meant the samples had not been produced at an accurate enough standard for use in the database. A new method of sample production was explored, developed and then implemented.

It was identified that although the screw micrometer was accurate enough for the production of sample cans for colour matching, the accuracy required for the production of database samples was far higher. Therefore it was necessary to weigh the ink to be applied to the IGT printability tester using scales measuring with a resolution of 0.01mg.

Therefore, again using trial and error, it was identified that in order to achieve 0.00997g of ink on the Leneta card, 0.3g of ink needed to be applied to the IGT printability tester. Database samples could now be produced with a high enough accuracy for the formulation system to work properly.

4.2.1.2 Sample production

Due to the accuracy required for the database samples, as highlighted above, it was essential that an accurate and repeatable method was used to ensure consistency.

Samples were required for all fifteen colorants, black, white opaque and white transparent, a complete list is itemised in Appendix 3. The transparent sample was only required once as the colour could not be altered by increasing the amount used. The concentrations of the other colorants are shown in the table below. In addition, one sample had to be produced which contains 4% black and 96% colorant to give the software details about the effect that black has on the colour and the absorption and scattering coefficients. All the percentages chosen were typical of levels used during formulation.

Transparent (%)	Colorant (%)
98	2
96	4
92	8
85	15
70	30
40	60
0	100

In order to maintain simplicity, 10 grams of ink was mixed for each sample, allowing easy conversion between percentage and weight. Again, the ink was weighed by using scales measuring to an accuracy of 0.01g.

Weighing of the ink for mixing was achieved by placing the standard ink container on the scales and zeroing the display. Ink was then removed until the display showed the negative value required, for example -0.2g. This was repeated for both the colorant and the required amount of transparent. The colorant and transparent were then mixed, by hand, using a mixing spatula. The decision on whether the ink is thoroughly mixed is down to the person performing the mixing and it was therefore important to ensure consistency in the process. Typically a sample was mixed for 5 minutes to ensure a consistent mixture and hence relevant printed colour. This was repeated for all combinations of colorant and transparent ink, one colorant at a time.

Once the inks had been prepared, it was then possible to produce the samples. The first task was to measure out the correct weight of ink required to produce the required ink film thickness. This was achieved by placing a square of transparent film onto the scales (measuring to an accuracy of 0.01mg) and zeroing so the scales read 0. Ink was then applied to the transparent film until it read 0.3g, accuracy being of utmost importance. The transparent film and ink were then removed from the scales. The ink was then applied to the top roller on the IGT printability tester, ensuring all ink was removed from the transparent film, and distributed for approximately 30seconds to ensure even coverage [30]. The printing disc was then brought into contact with the distribution rollers and distribution was continued for a further 30seconds.

Whilst the ink was being distributed, the scales were reset and a clean Leneta card was weighed and recorded. Once the distribution of the ink had taken place, the printing disc was removed from the distribution rollers and readied for printing. The weighed Leneta card was then placed on the printing guide. With everything in place, the printing disc was brought into contact with the printing guide to a pressure of 300N and the print was made. A printing pressure of 300N was used as previous preliminary prints had identified this pressure as giving a good clean print without any patchiness.

The Leneta card was then reweighed and a note of the new weight was recorded. The sample was finally placed into an oven at 160°C for 10 minutes to dry. Once the sample was dry it was removed from the oven, ensuring no contamination of the print, for example by fingerprints. The weight of ink transferred to the sample was calculated by simple subtraction, to ensure approximately 0.00997grams had been printed, this weight was then recorded on the reverse of the sample. This was repeated for all required samples.

4.2.1.3 Sample measurement

All the samples were measured into the ProPallete software using the spectrophotometer. The first action required was to set up the database so that it was specific to the process, which required selection of system parameters.

The use of the Leneta panels allowed contrast measurements to be entered into the system, measurement of both the over light (white) and over dark (black), for each ink, which as previously mentioned are required for the determination of the absorption and scattering coefficients for semi-transparent layers. For this to be achieved, both the white and black surfaces of the Leneta card needed to be measured before any of the samples could be entered. The reason for this is that for semi transparent layers, the reflected light from the surface of the ink layer will not only have been absorbed and scattered by the ink layer when incident to the surface, but will have undergone the same after reflection from the substrate surface described in Chapter 2. It is therefore important to understand the reflection properties of the substrate, allowing the system to incorporate this into the required calculations. Once this had been entered and the user preferences chosen, it was then possible to measure the database samples.

As with all measurements taken with the spectrophotometer throughout this project, an average of three readings was used to reduce any variations in the print. The spectrophotometer settings were automatically applied by the formulation system and a suitable UV filter was chosen to eliminate any UV effect (as the inks used contain no UV elements, this was not an issue). The initial measurements required were of the resin, in this case the transparent white, followed by the colorants, including the black and opaque white. For all measurements, the film weight had to be set at $1.5 g/m^2$. Each colorant was entered separately and any major errors were highlighted by displaying the calibration data, which predicts how different the sample is from the target colour. As previously mentioned, when the samples are measured for each of the colorants, the system will determine the absorption and scattering coefficient at different wavelengths for the different colorant concentration levels. As the information for each colorant is built up, the system, using linear regression is able to calculate the error for each sample by assessing the deviations of each data point from the regression line. This allowed any samples displaying large errors to be remade without redoing the whole sample set. Once all the samples had been entered and acceptable calibration of the data had been achieved, the database was then saved in the appropriate format ready for testing.

4.2.1.4 System testing and application

To highlight not only the accuracy of the database, but also the capability of the formulation system for this particular application, testing was carried out. The initial tests performed included formulations on both clear and white basecoat cans using a known transparent ink formulation.

Ink was mixed using a combination of three of the inks displayed in Appendix 3, as well as a percentage of the transparent white in order to produce a target colour. Once this had been achieved, white and clear basecoat cans were printed at a coverage of 1.5g/m^2, using the IGT printability tester. These cans were then dried in the production ovens, but were not passed through the over varnisher, thus removing any colour variation caused by the over varnish.

The samples were measured into the system and a formulation was created using the procedure described in Appendix 5 (formulation manual). The formula created by the system was compared to the original to highlight the accuracy of the database and system. The formulation system created all possible combinations of ink in order to match the original target. Although none of the combinations matched exactly, some of the suggested formulations used differing inks and those containing the same inks had only very slight differences in the percentages of each, they were not vastly different. Several of the suggested formulas were mixed, printed and then compared to the original. The results proved to be almost identical, with a ΔE no larger than 2, with most of the variation being displayed in either the L or C component. The variation in the L or C component would generally be associated with the variation in ink film thickness, therefore the ΔE value could be reduced by simply reducing or increasing, very slightly, the quantity of ink printed. However, a ΔE of 2 or under is acceptable when colour matching and the difference between the two would be almost undetectable under general comparison. Since the results gained from this simple test were acceptable, further testing of the system could be carried out.

The next test to be carried out was the use of opaque colours on clear basecoat. This required the use of the opaque white rather than the transparent as this removes the effect of the can finish, similar to that of using a white basecoat. The test procedure was carried out in exactly the same manner using the transparent white and the results are detailed below.

Several attempts were made, using numerous mixed colours, to gain an acceptable match, none of which came within acceptable limits, even after correction formulations had been performed. After identifying that there had been no mistakes made with the test procedure, initial reasons for the poor results were identified.

The database, as mentioned earlier had only been produced using percentages of base colorants and transparent white. It had been assumed that the system would simply replace the transparent white with the opaque in order to produce an acceptable match and that the data entered for the opaque white would be sufficient. This, however, was not the case and the testing of the system had shown that the opaque white actually affected the colour of the inks in a different way to that of the transparent. The opaque white had the effect of 'dirtying' the colour, which simply reduces the strength of the colour as well as making it appear darker (making it duller). Since the database contained no information concerning this effect, the system was unable to produce the required accuracy of formulations. It was therefore required that suitable database samples were produced incorporating percentages of colorant and opaque white.

The samples were produced in the same manner as those using the transparent white, except for a few simple changes. Firstly, the weight of ink required for the production of samples at $1.5g/m^2$ was modified to allow for the higher physical density of the opaque white. Secondly, instead of producing seven samples per colorant, only five were produced, the percentages of which are displayed below:

Opaque (%)	**Colorant (%)**
0	100
5	95
15	85
30	70
60	40

The reason for the reduced number of samples was due to the fact that it was still unknown whether this would remedy the problems associated with the use of the opaque white. In producing fewer samples, it would be possible to test the system to see if any improvement had been achieved. If so, further samples could then be made if required.

The samples were measured into the system using the same procedure as before, except the opaque white was entered as an alternative resin rather than a colorant, thus giving the effect of two connected databases. Once this had been achieved, the system was retested.

The results gained on this second attempt were far better than using the previous database and gave acceptable results, giving a maximum ΔE of three, for most matches and formulations. Although this was still not as good as the results gained for the transparent white, it had shown that the production of these samples had improved the system. One of the reasons for the differences in accuracy between the opaque and transparent formulations can be highlighted by the spectrophotometer settings. The inclusion of the specular component in the measurement of the target and substrate will give increased reflectance at all wavelengths. However, when using the opaque, the influence of the substrate is partially or fully hidden thus the effect of the spectral reflection is reduced leading to what appears or is measured to be a darker colour. This is one of the inherent problems when selecting a single measurement geometry. If more time had been available, it would have been advantageous to re-measure the opaque database samples into the formulation system using a separate database in the specular excluded mode and then repeating the testing using the different mode to ascertain if there was any improvement. This would have had the effect of removing the variations in the specular reflection from the surfaces measured. However, with the system working within acceptable limits, it was then possible to test its accuracy using a colour target required for production.

Customers will specify the colour requirements for designs with the use of 'colour targets'. These 'colour targets' can be anything from a specified pantone number (see Chapter 2), to a tin plate proof. It was in matching these colour targets that the limits, but not failures, of the system were identified.

Although the system performed very well in matching some colour targets both visually and numerically, such as the pantone colours as shown in Appendix 6 (targets were measured directly from the pantone book) and the tin plates, other targets such as plastic aerosol tops, gave less accurate visual matches, even after corrections had been performed.

The reason for this is due once again to the spectrophotometer settings. As mentioned in Chapter 2, spherical spectrophotometers are able to measure both the diffuse and specular reflection for a surface. Throughout this project, the specular included mode of the spectrophotometer was used. The amount of specular reflection from a surface will vary depending on the type of surface. In the case of the some of the targets mentioned above, specifically the plastic aerosol tops, the amount of specular light reflected from the surface will be minimal. This is because the surface of many plastics is not as highly reflective as metallics, light is more readily absorbed and in some cases passes through the material during measurement. This means that the amount of reflected light is reduced, in turn making the measured sample appear darker. This was confirmed by the results gained when creating a formulation using a similar sample. Although the formulation system had produced a sample that had the correct hue, differences were perceived in the lightness and chroma. The formulation colour produced was too dark and the colour was less saturated, which highlighted the fact that the spectrophotometer had perceived the colour to be darker. It also indicated that the formulation system was not at fault as the formulation matched to the perceived colour of the spectrophotometer reading and only the visual assessment was different.

The easiest way to remedy this problem is to use only suitable colour targets for the production of formulation, or devise some means of obtaining suitable measurements by standardising the measurement procedure as with the measurement of colour densities on paper [11]. This could take the same strategy as density measurements, whereby measurements are taken using a suitable standardised backing to the target and the effect of this backing is then removed for subsequent calculations.

Another option that will be detailed in the recommendations section of Chapter 5 will be to assess the effect of excluding the specular reflection on both the perceived and measured colour produced from the formulation.

4.3 Closure

This chapter has highlighted the requirements of a formulation system and detailed the process and pitfalls of producing a suitable database to gain suitable matches. Also highlighted are the achievements and uses of the system as well as the inherent failures due to colour measurement techniques.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The purpose of this chapter is to state conclusions drawn from work presented in this thesis, and provide recommendations for further investigation.

5.2 Conclusions

An investigation was carried out into the process of can decoration to determine current process capability and implement actions/systems required to improve performance and consistency. This involved the systematic investigation into process parameters, the conclusions of which are stated below.

Spherical spectrophotometry using the specular included reflectance although helpful to illustrate the highly reflective nature of the majority of can decoration, has inherent problems when used for opaque formulations.

The can decoration process is stable, with colour variation throughout production not exceeding a ΔE of 2. A ΔE of 2 would only just be visible to the untrained human eye. However, production tolerances, as measured from selected Tripticos, have been shown to be too variable. Some of the tolerances have been set too tight and cannot be achieved by the process. Each design should be assessed during normal production to identify the natural variation. Combined with the customer acceptance levels, the tolerances should be set accordingly. Tolerance limits set at a ΔE of 2.5 for all measured production samples are achievable.

The ink saturation point was found to be at an ink film weight of $1 g/m^2$. The optimum ink film weight required for colour saturation without excessive ink usage was found to be $1.5g/m^2$. An ink film weight of $1.5g/m^2$ will also maintain colour consistency throughout production. The creation of a suitable formulation database was successfully carried out using a film weight of $1.5g/m^2$.

No single variation in a process parameter explored, during normal production, is large enough to cause colour variation in excess of suggested tolerances.

Suitable formulations can be created using the formulation system. A ΔE of 2 or less with respect to the target colour is achievable after two attempts for the majority of formulations. However, limits, inherent to the system mean it is not yet a complete solution.

5.3 Recommendations

Detailed below are recommendations for future work for the continued development of the can decorating process, as well as the formulation system.

Highlighted in this thesis was the need for further automation/modernisation of the printing press. This would enable further, more detailed, work to be carried out identifying the effect of those press parameters not covered in this work. Automation would also increase production time.

Further instruction should be given to appropriate staff educating them on the findings and recommendation of this thesis.

Development of a measuring standard is required to enable accurate formulations to be maintained regardless of the colour target. This could be in the form of some variety of highly reflective backing, which could be applied to the colour target.

The performance of the formulation of opaque samples should be tested using the specular excluded spectrophotometer mode.

Continued improvement and development of the database should also be maintained to ensure similarity to production.

APPENDICES

APPENDIX 1

A1.1 IGT Printability Tester

The IGT C1-5 printability tester consists of a printing unit with an integrated inking unit and printing form, see Figure A1.1 below. The tester was developed to print reproducible strips of substrate using offset inks to determine ink transfer in g/m^2.

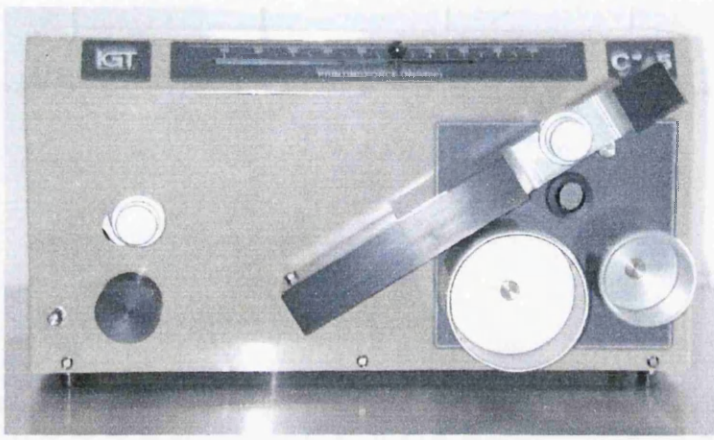


Figure A1.1 IGT printability tester

The tester was modified to allow direct printing onto various diameter cans allowing a direct comparison between the tester and the production line. These printed cans, can then be used for measuring colour with spectrophotometers, making them ideal for colour-matching systems or controlled laboratory experimental investigations.

The tester consists of two distinct parts. The first of these is that of the inking unit. This consists of two metallic cylinders of different diameters, on top of which a top roller is mounted. One of the metallic cylinders is driven with an electric motor, while the other cylinder is driven by the top roller and is allowed to oscillate in an axial direction. The unit is inked by applying a specific quantity of ink to the top roller with the use of a precision inking pipette. The inking pipette is similar to that of a screw micrometer and allows ink to be applied to the inking unit in increments of 0.01ml, thus allowing very accurate and repeatable ink amounts to be applied to the unit. This ink is then distributed evenly across the inking unit cylinders aided by the axial movement of the cylinder. Once the ink has been evenly distributed, the printing disc is then brought into contact with the top roller thus allowing the ink to be evenly applied. The whole process of inking the printing disc takes no longer than a minute after which the printing disc can then be transferred to the printing unit of the tester.

The printing unit of the tester consists of the printing disc or actual printing form (similar to that of the printing blanket on the production lines) and an impression cylinder or mandrel, onto which the can is placed. By adjusting the size of the impression cylinder and printing disc, all variants of can sizes can be printed. Once a can has been place onto the impression cylinder, then the printing disc can be brought into contact with the can allowing a print to be made. The print speed of the tester is set at 0.3m/s, but the printing force is variable between 100 and 1000N.

A1.2 Determination of Ink Transfer

Although a known amount of ink is applied to the inking unit, the exact amount transferred to the can is not known. In order to determine the ink film thickness applied to the can, the amount of ink transferred must be measured. Detailed in Appendix 2 is a description of initial attempts to identify printed film thickness without the use if the adapted IGT printability tester, which allowed prints to be produced directly onto cans.

The easiest way to measure ink transfer is by weighing the can before and after printing. This will determine the weight of ink on the can. As the area printed is also known it is easy to determine the weight per unit area (g/m^2). The quantity of ink printed is very small in comparison to the weight of the can. It was, therefore essential that a balance, which resolves weight to 0.1mg, was used.

On knowing the weight of ink transferred and the density of the ink, which can be calculated by weighing out a known volume, it is then a simple calculation to determine the ink film thickness. However, this will only give the wet film thickness and not the true dry film thickness. To determine the dry film thickness, the percentage volume of solvent needs to be removed. As the ink is 20% solvent by volume, all that is required is to reduce the weight by 20%, to give the dry film thickness.

In order to identify the consistency and accuracy of results gained for the above characterisation of the IGT printability tester, a second procedure was also used to confirm the ink film thickness produced. This used a non-contact measurement technique in the form of white light interferometry. The results of both procedures are displayed below.

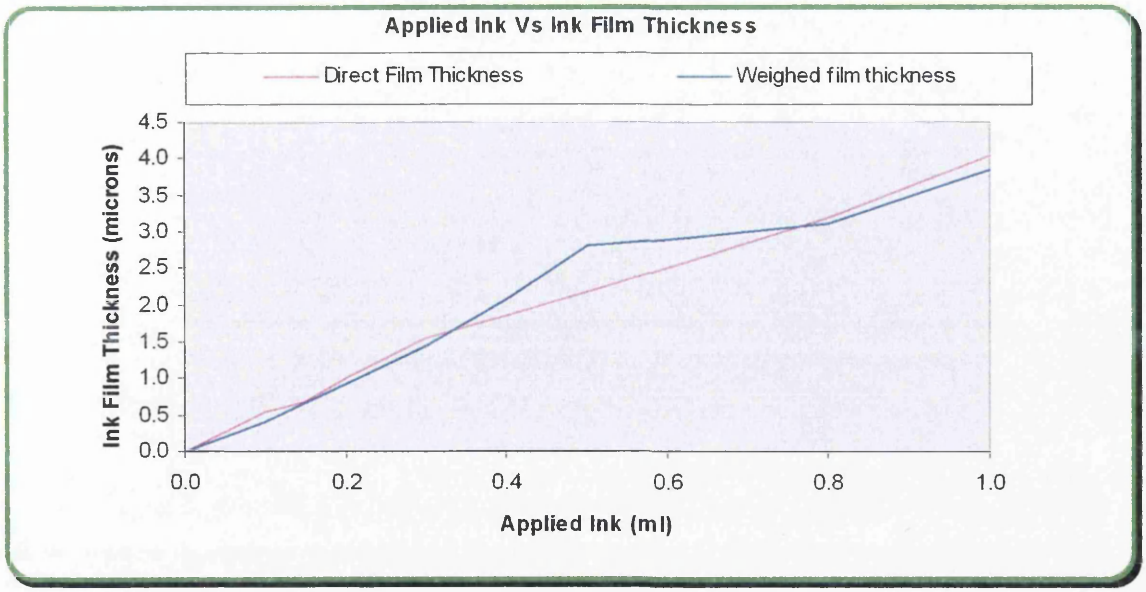


Figure A1.2 Applied ink Vs In Film Thickness

With the exception of one point, the results show good consistency. From the results presented above, a best-fit line was used to give quick reference allowing easy conversion between applied ink and ink film thickness, this is displayed below.

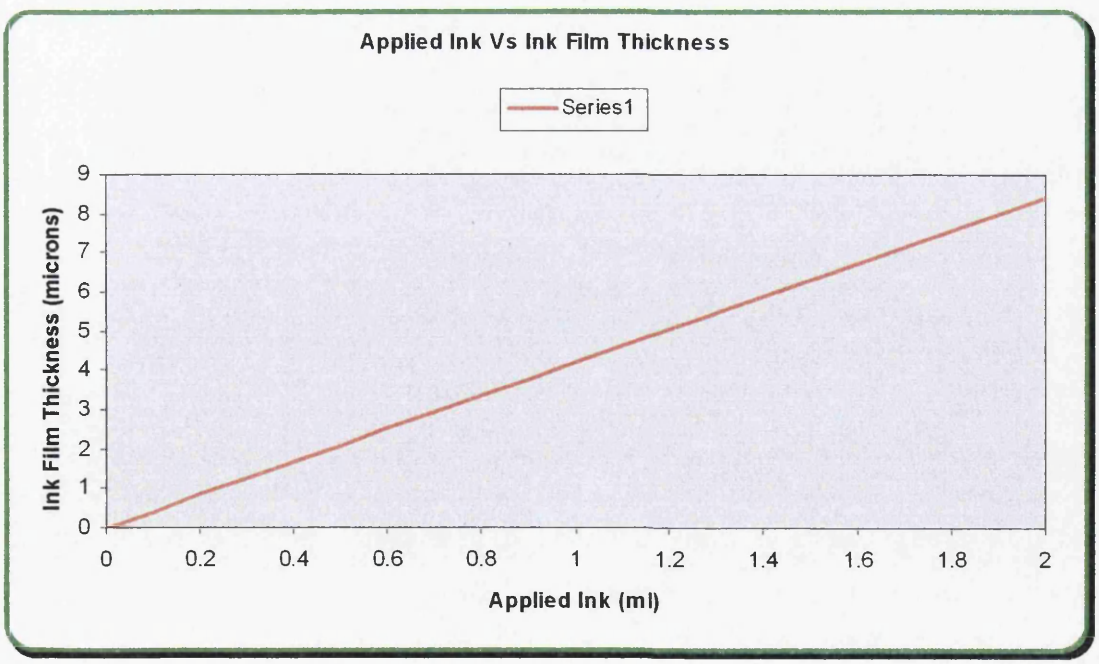


Figure A1.3 Best Fit Line

APPENDIX 2

A2.1 Variation of Colour with Ink Film Thickness

A2.2 Introduction

This investigation was carried out to investigate how colour varies with increasing ink film thickness. Colour variations are observed through out the print run, even though the ink formulation remains the same throughout. It is, therefore, believed that the colour variation is due to the varying ink film thicknesses printed during the print run. With this in mind it was decided to investigate this variation.

The investigation was to be carried out using the IGT F1 printability tester, based at the University. This introduced several problems, which took time to overcome. The first of these was that of a suitable alternative substrate, as the aluminium cans produced at Envases were not only too rigid, but also too small to be used on the tester. The alternative substrate used was that of 0.2mm aluminium shim, which was obtained through Aalco, this proved ideal for the application.

Another problem, which became apparent during testing, was that associated with the base coat. Ideally, a white base coat needed to be used to produce a standard base colour from which to work. This means that a very high base coat thickness is required in order eliminate the underlying colour of the aluminium. The initial idea was to apply the base coat as if it were ink, i.e. use the IGT tester. This however proved impossible as the white base coat dried far too quickly during the inking process, becoming a powder. The K-bar[ref] tester was then used as an alternative. This would mean applying several coats of the base coat in order achieve the base colour required. This also proved impossible, as once again the ink was drying far to quickly, producing ridges on the sample. It was therefore decided to use a clear base coat, which would not require such a thick coating, for obvious reasons.

A2.3 Method

The production of samples for colour measurement was two-fold. The first task was to apply the base coat and the second to apply the ink. The base coat, as previously mentioned, was applied using the K-bar. Before the base coat could be applied, the samples had to be cleaned using solvent in order to remove any excess dirt from the surface. Once this had been completed, the sample was placed onto the K-bar tester and the tester set-up for application. The base coat was applied to the sample and the K-bar drawn down at a speed setting of four. Once this was completed, the sample was placed into an oven at 126°C for 10 minutes. This was continued until enough samples had been produced. The samples were then cut in half lengthways in order to produce a sample the correct size for the IGT tester.

The IGT tester was used to apply varying amounts of ink to the samples. The set-up of the IGT tester takes a relatively long time, and requires cleaning after each sample. The sample is set-up on the tester and printing cylinder can then be inked. This is achieved by applying a known quantity of ink to the inking unit, which in-turn spreads the ink evenly over the rollers before applying it to the printing cylinder. Once the cylinder has been inked, it is placed on the printability tester in order to print onto the sample, which is achieved by applying the printing pressure (500N) and then powering up the motor. Once the motor has been powered up (0.4m/s), the print can be made. Once the print is complete, the sample was placed into an oven at 126°C for 10 minutes in order to cure the ink. This was continued for varying quantities of ink.

The samples were then measured using the spherical spectrophotometer, using D_{50} and 2° observer. Three measurements were taken on each sample to gain an average result.

APPENDIX 3

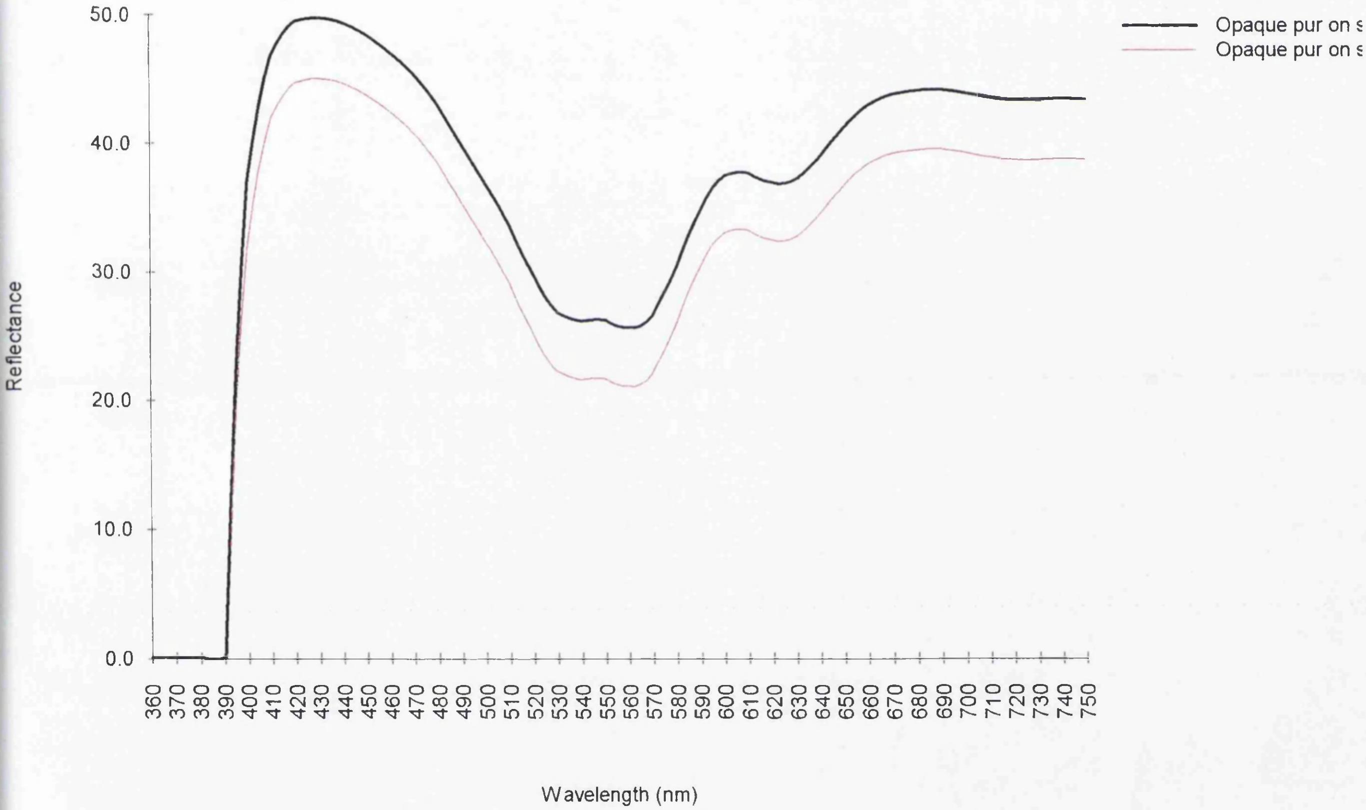
A3.1 DATABASE INKS

COLOUR	CODE	BATCH	PROD	EXP.
TRANSPARENT	TZ-1062 (1.5% TN-0015)	02/28585	02/04/02	04.04
BLACK	157959	83544		11.02
WHITE OP.	TZ-1028	02-25210	27/11/01	11.03
VIOLET PMS	158302	390012		11.03
RUBIN RED C.	157962	01/	01/08/01	
BLUE PROCESS	157960	387933		01.04
YELLOW PMS 012	158303	76845	10/11/98	
YELLOW C	158411	381407		01.04
GREEN PMS	158049	528293/370532		03.03
SP40 ORANGE	TZ-3800	02-28711	08/04/02	04.04
MAGENTA PROCESS	158298	75327	08/07/98	
RED PMS 032	156358	76851	05/11/98	
BLUE REFLEX	157961	82304		06.02
RED WARM	157957	83654		11.02
YELLOW PROCESS	157898	81806		04.02
BLUE 072	158789	390068		11.03
CYAN PROCESS	158299	81205		02.02
PURPUR PROCESS	158048	76012	09/10/98	

APPENDIX 4
REFLECTANCE DATA

Equation: CIELCh - CIE94 1.00:1.00
Observer: 10°
Illuminant: D50
CE-7000A - XA0933
Status: DREOVV
STANDARD: Opaque pur on silver bc (incl)
MEASUREMENT TYPE: Reflectance

	Illum	L*	C*	h°	DL*	DC*	DH*	DE*
Standard	*Illum*	*L**	*C**	*h°*				
Opaque pur on silver bc (incl)	D50	63.292	21.732	302.571				
Trial	*Illum*	*L**	*C**	*h°*	*DL**	*DC**	*DH**	*DE**
Opaque pur on silver bc (excl)	D50	59.372	23.521	303.023	-3.921	0.905	0.135	4.026



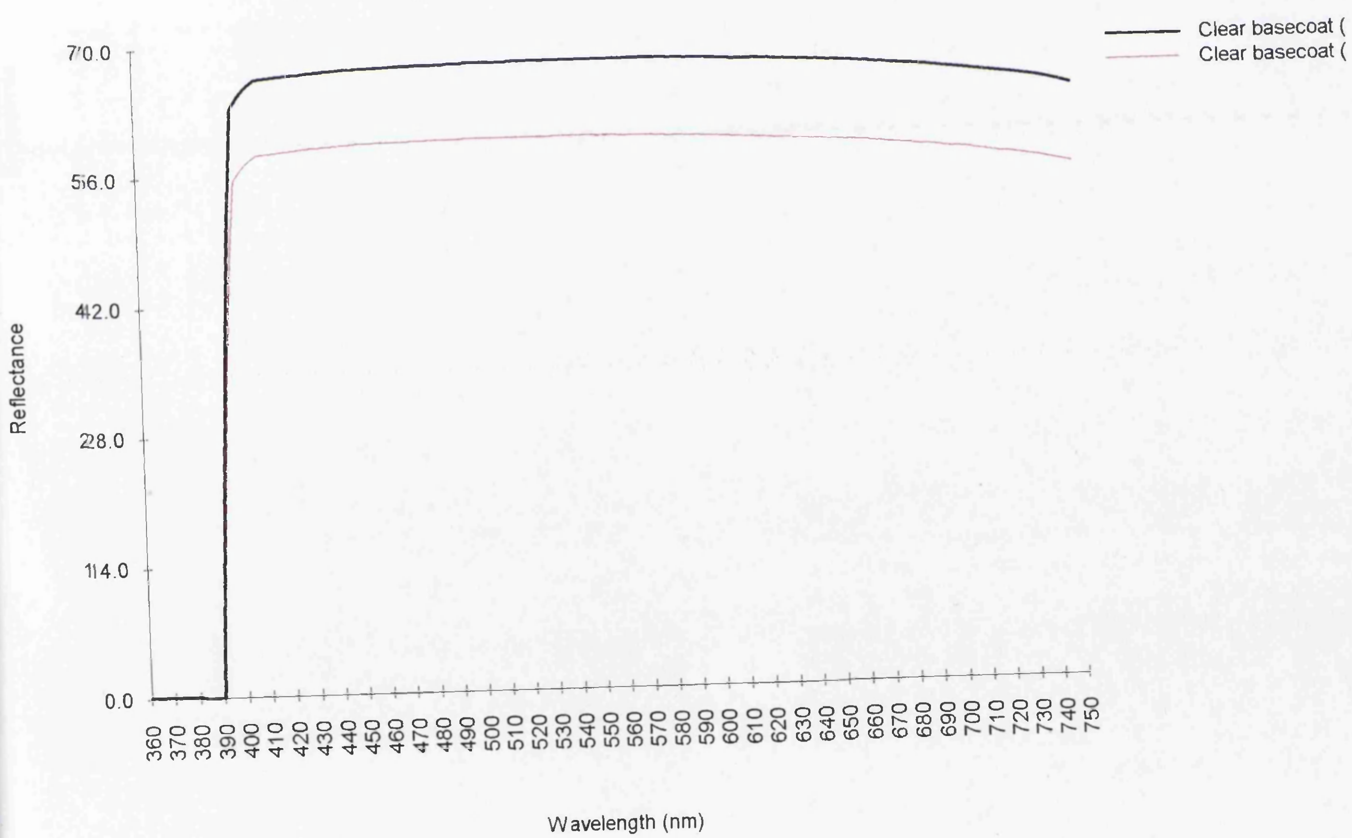
16/11/04
Equation: CIELCh - CIE94 1.00:1.00
CE-7000/A - XA0933
STANDARD: Clear basecoat (incl)

ENVASES UK LTD
Optiview Quality Control Version 5.1
Observer: 10°
Status: DREOVV

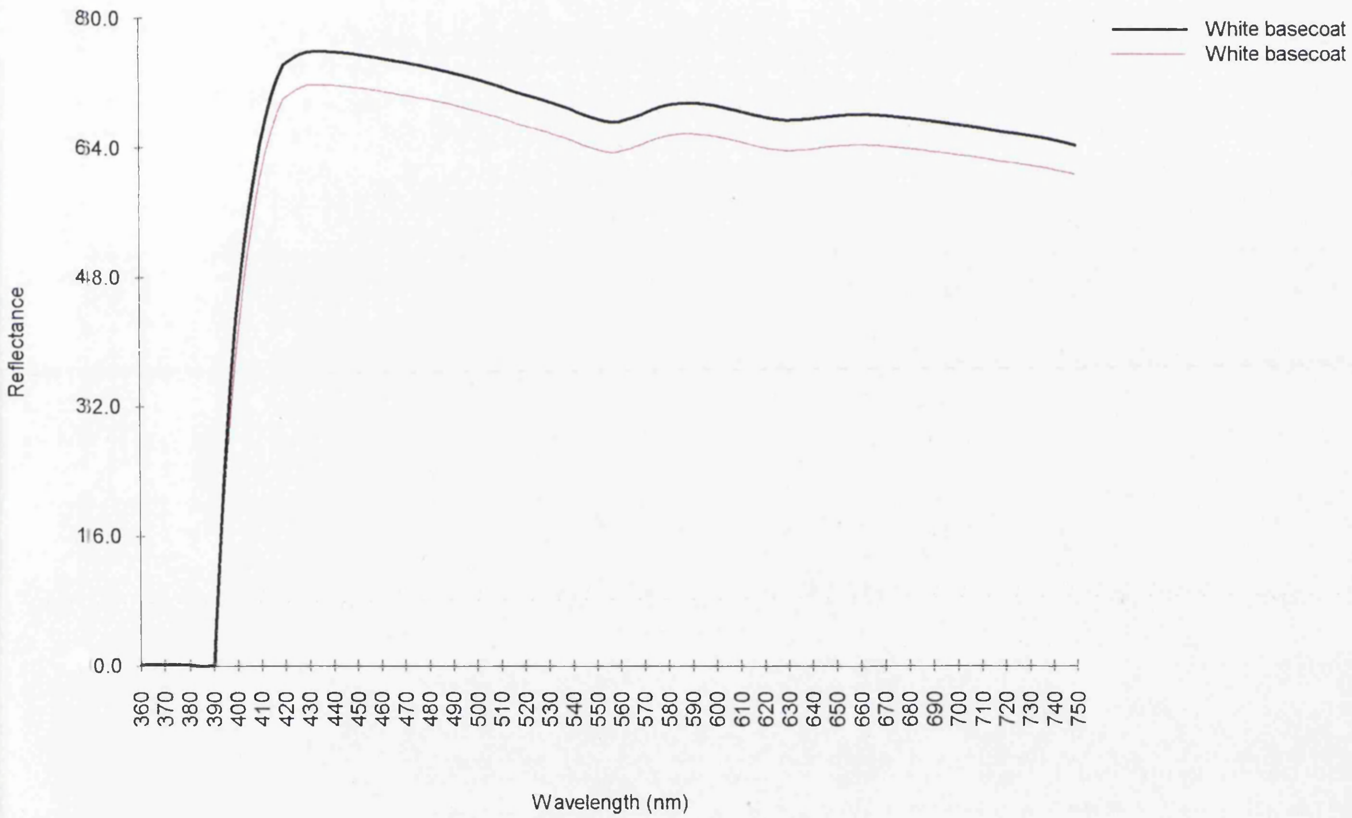
14:50
Illuminant: D50

MEASUREMENT TYPE: Reflectance

	Illum	*L**	*C**	*h°*	*DL**	*DC**	*DH**	*DE**
Standard Clear basecoat (incl)	D50	85.830	0.482	134.076				
Trial Clear basecoat (excl)	D50	81.457	0.545	155.111	-4.373	0.062	0.186	4.377



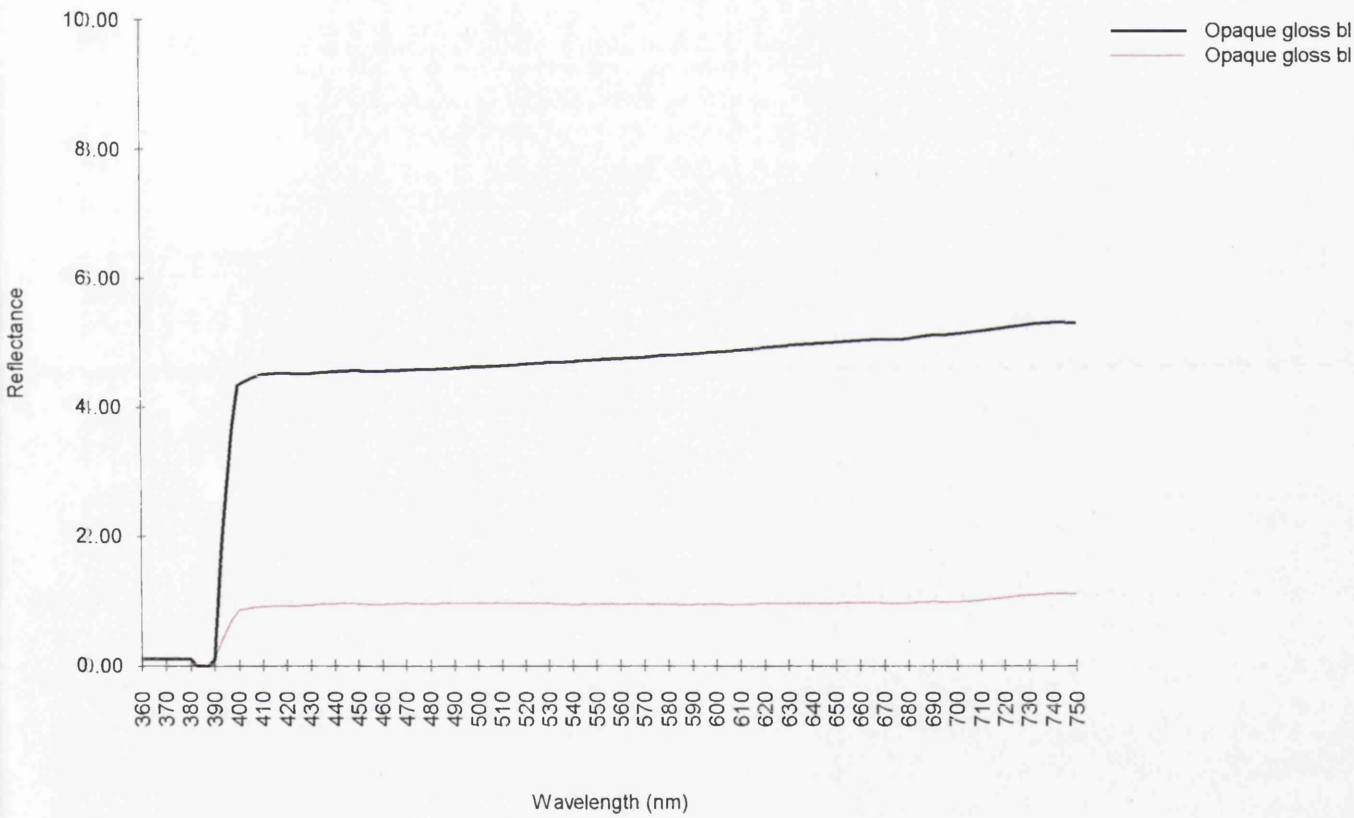
Standard	*Illum*	*L**	*C**	*h°*				
White basecoat (incl)	D50	86.704	4.219	266.559				
Trial	***Illum***	***L****	***C****	***h°***	***DL****	***DC****	***DH****	***DE****
White basecoat (excl)	D50	84.770	4.134	266.260	-1.934	-0.071	-0.020	1.935



ENVASES UK LTD
Optiview Quality Control Version 5.1
Observer: 10°
Status: DREOVV

16/11/04 | 14:48
Equation: CIELCh - CIE94 1.00:1.00 | Illuminant: D50
CE-7000A - XA0933
STANDARD: Opaque gloss black (incl) | MEASUREMENT TYPE: Reflectance

Standard	*Illum*	*L**	*C**	*h°*				
Opaque gloss black (incl)	D50	26.009	1.177	57.624				
Trial	*Illum*	*L**	*C**	*h°*	*DL**	*DC**	*DH**	*DE**
Opaque gloss black (excl)	D50	8.565	0.118	137.504	-17.445	-1.006	0.470	17.480

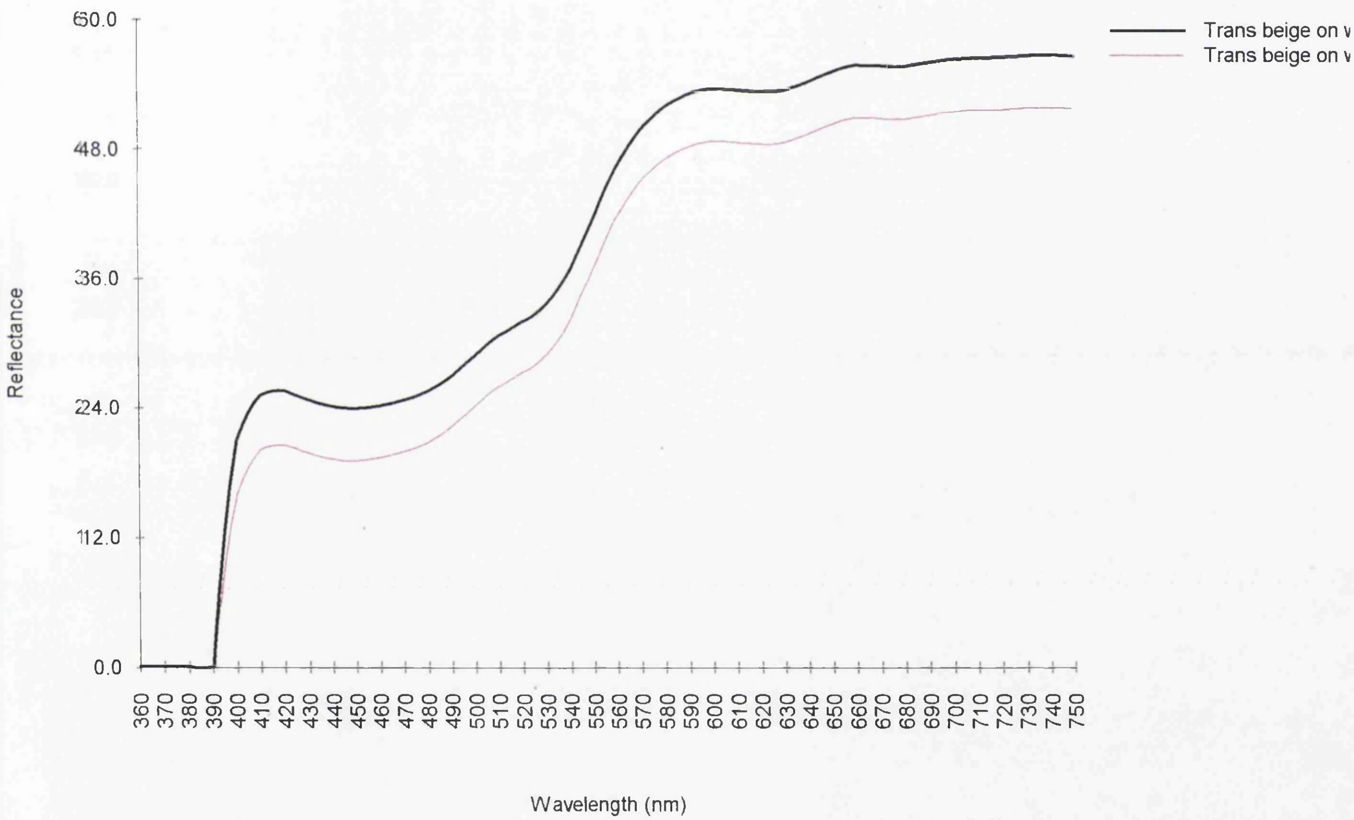


ENVASES UK LTD
Optiview Quality Control Version 5.1
Observer: 10°
Status: DREOVV

16/11/04
Equation: CIELCh - CIE94 1.00:1.00
CE-7000A - XA0933
STANDARD: Trans beige on white bc (incl)

14:43
Illuminant: D50
MEASUREMENT TYPE: Reflectance

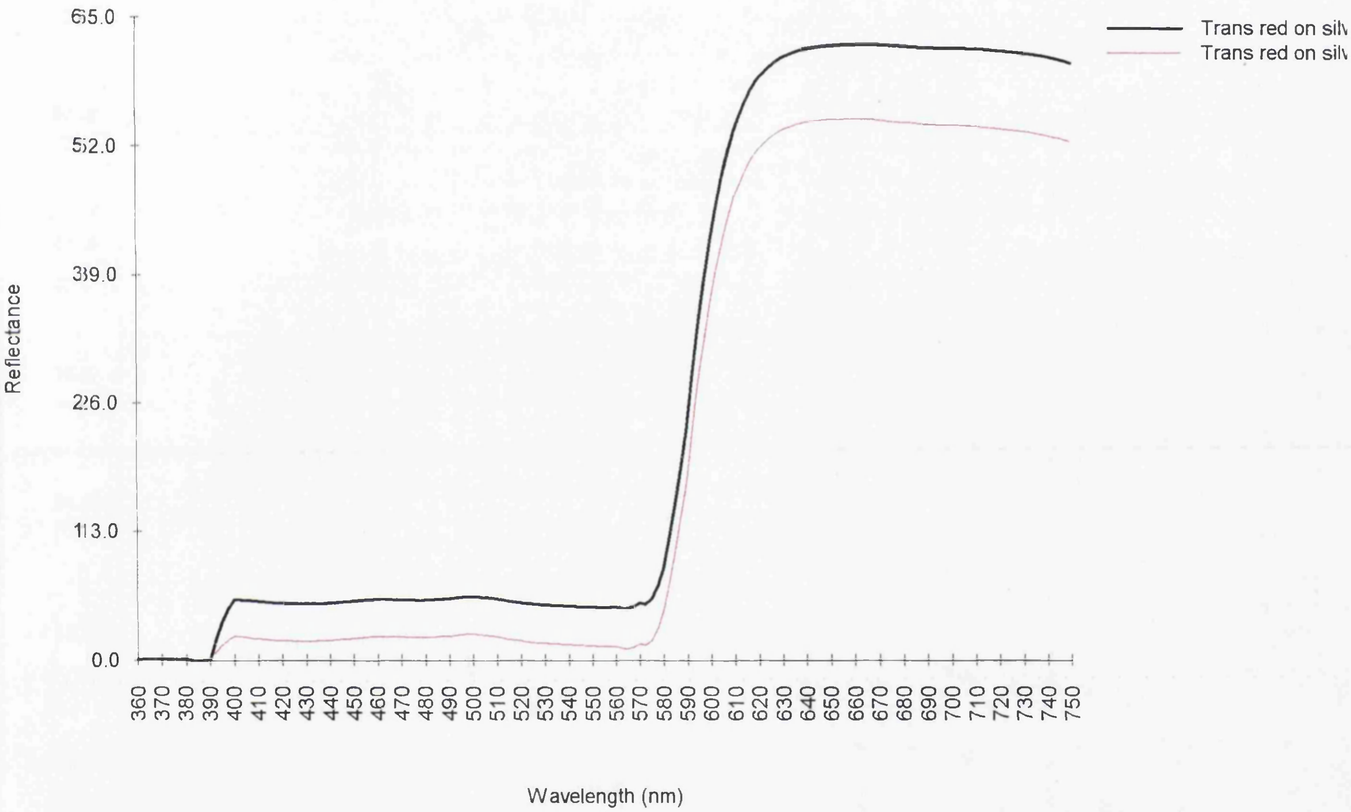
Standard	***Illum***	***L****	***C****	***h°***				
Trans beige on white bc (incl)	D50	71.140	27.490	63.127				
Trial	***Illum***	***L****	***C****	***h°***	***DL****	***DC****	***DH****	***DE****
Trans beige on white bc (excl)	D50	67.689	30.462	64.112	-3.451	1.329	0.352	3.715



CE-7000A - XA0933 Status: DREOVV

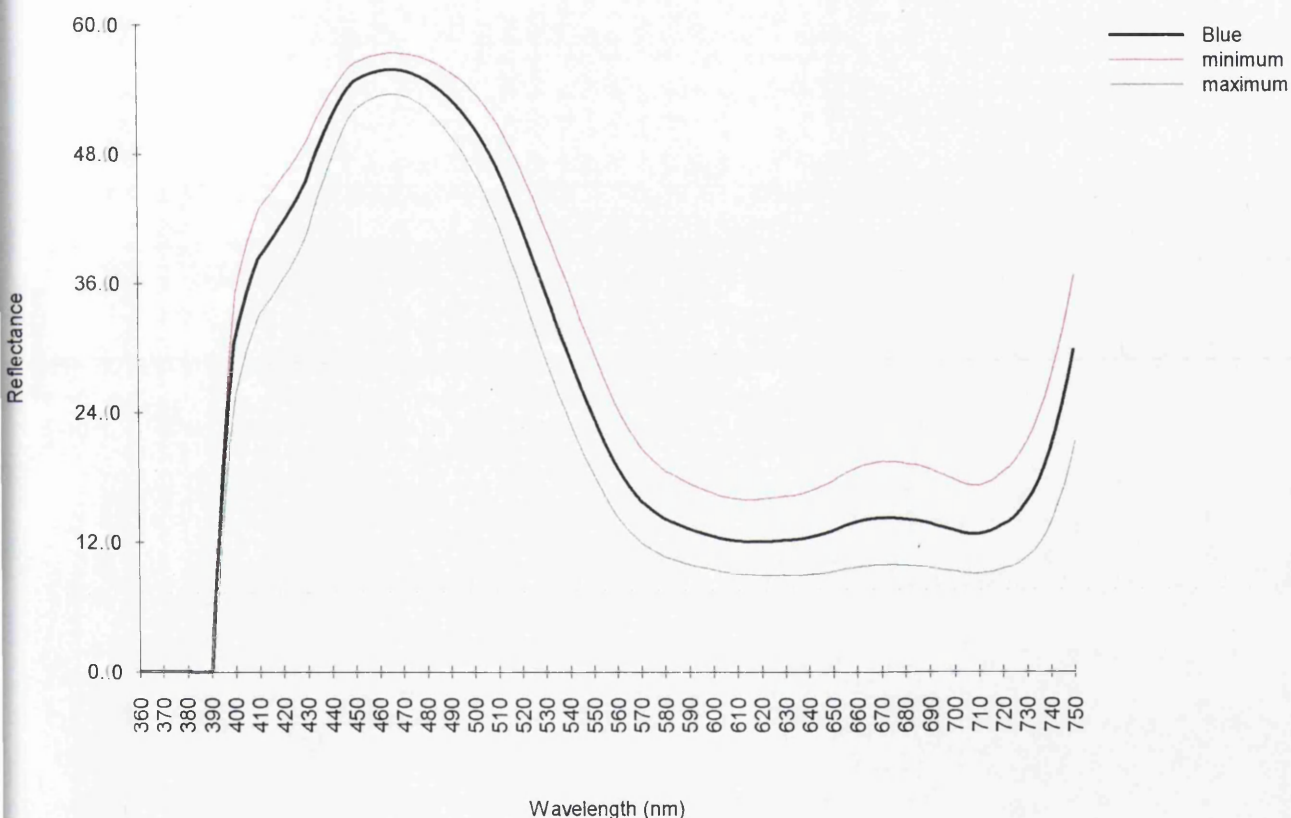
STANDARD: Trans red on silver bc (incl) **MEASUREMENT TYPE: Reflectance**

Standard	*Illum*	*L**	*C**	*h°*				
Trans red on silver bc (incl)	D50	47.629	61.552	30.833				
Trial	***Illum***	***L****	***C****	***h°***	***DL****	***DC****	***DH****	***DE****
Trans red on silver bc (excl)	D50	41.038	72.775	35.815	-6.590	2.977	3.025	7.838



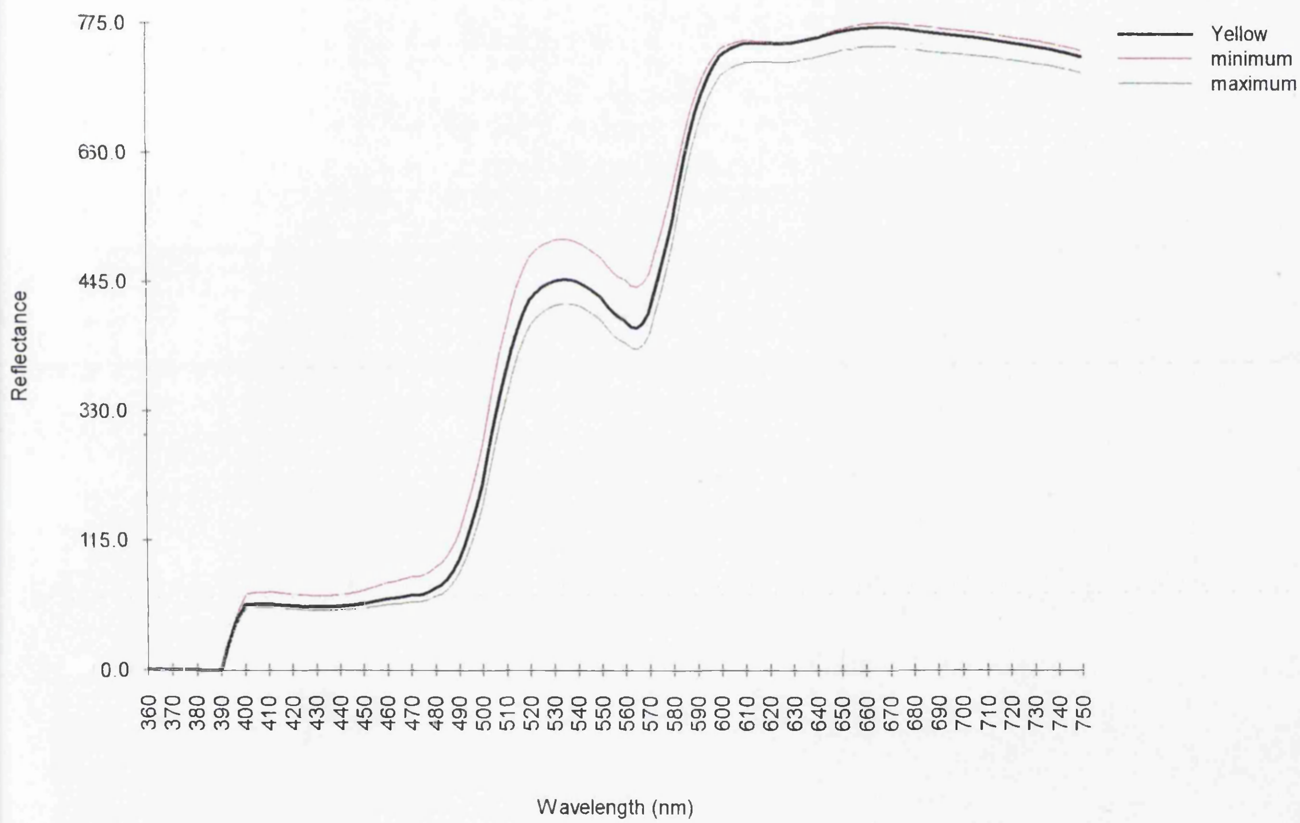
6/12/04 | Observer: 10° | 12:47
Equation: CIELCh - CIE94 1.00:1.00 | Status: CRIOVV | Illuminant: D50
CE-7000A - XA0933
STANDARD: Blue | MEASUREMENT TYPE: Reflectance

Standard	*Illum*	*L**	*C**	*h°*				
Blue	D50	58.455	40.672	232.414				
Trial	*Illum*	*L**	*C**	*h°*	*DL**	*DC**	*DH**	*DE**
minimum	D50	62.551	36.280	229.330	4.096	-1.552	-1.284	4.564
maximum	D50	53.988	44.078	235.609	-4.467	1.203	1.466	4.853



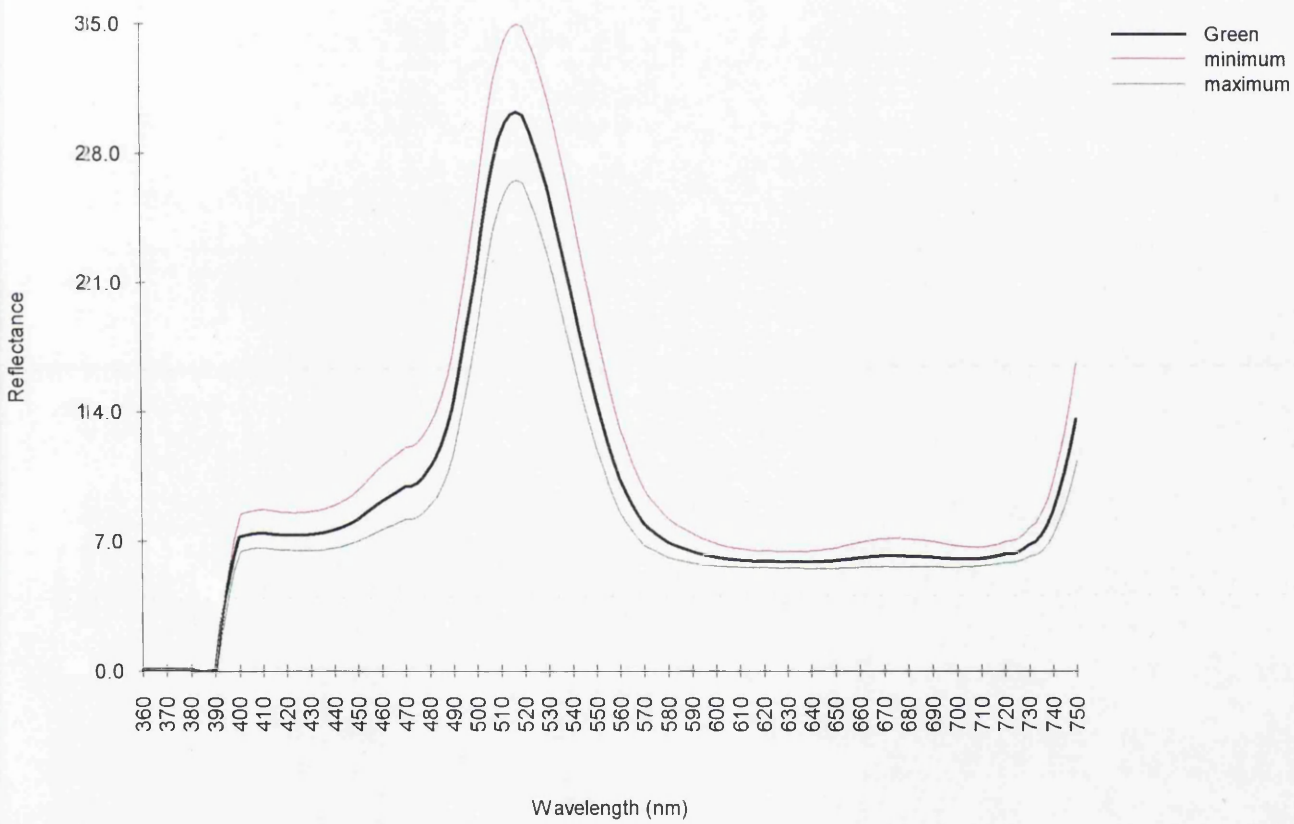
6/12/04 12:41
Equation: CIELCh - CIE94 1.00:1.00
Illuminant: D50
CE-7000A - XA0933
STANDARD: Yellow
MEASUREMENT TYPE: Reflectance

Standard	*Illum*	*L**	*C**	*h°*				
Yellow	D50	73.939	66.966	75.087				
Trial	*Illum*	*L**	*C**	*h°*	*DL**	*DC**	*DH**	*DE**
minimum	D50	76.068	64.160	78.039	2.129	-0.699	1.685	2.803
maximum	D50	72.355	67.191	73.990	-1.584	0.056	-0.641	1.709



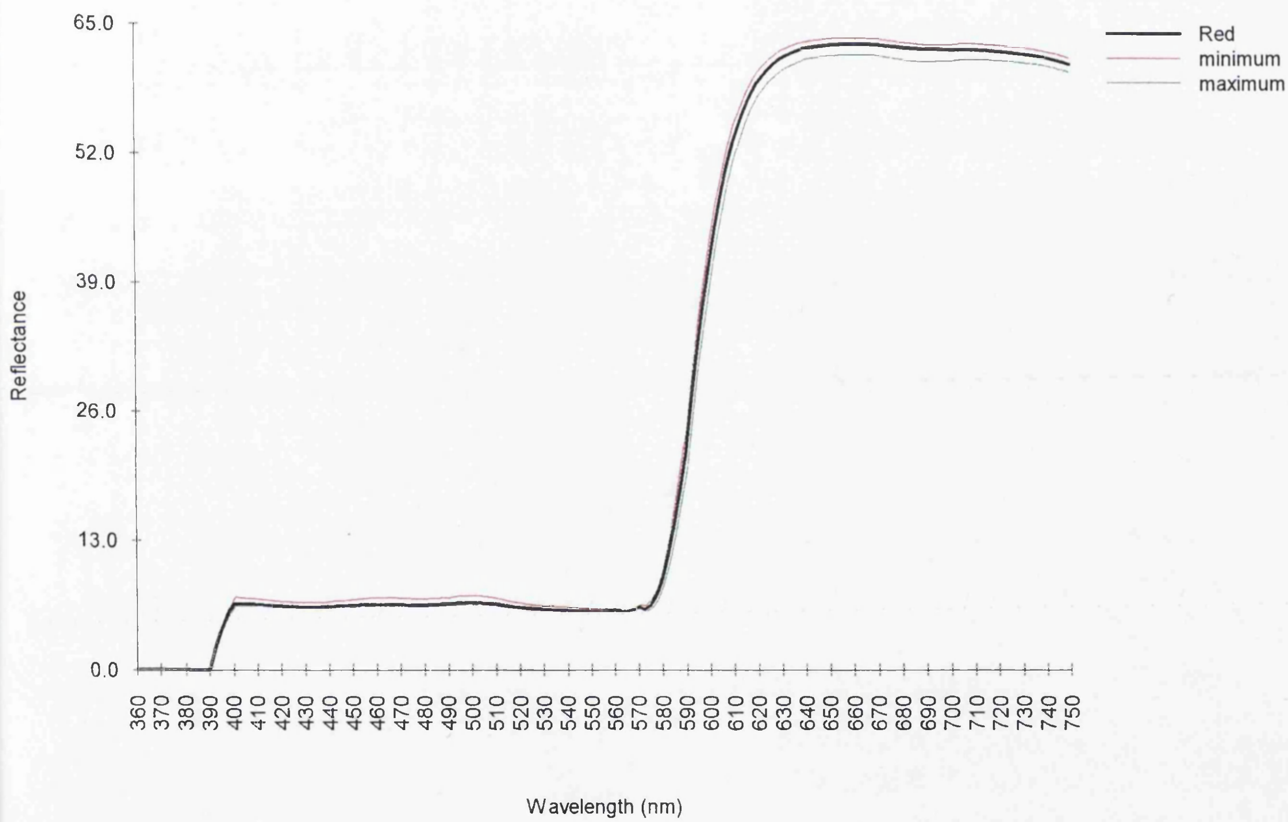
6/12/04 Optiview Quality Control Version 5.1 12:56
Equation: CIELCh - CIE94 1.00:1.00 Observer: 10° Illuminant: D50
CE-7000A - XA0933 Status: CRIOVV
STANDARD: Green MEASUREMENT TYPE: Reflectance

Standard	*Illum*	*L**	*C**	*h°*				
Green	D50	44.237	40.860	162.322				
Trial	***Illum***	***L****	***C****	***h°***	***DL****	***DC****	***DH****	***DE****
minimum	D50	47.797	44.197	162.680	3.560	1.176	0.165	3.752
maximum	D50	41.206	37.693	161.184	-3.032	-1.116	-0.483	3.266



6/12/04 ENVASES UK LTD 12:43
Optiview Quality Control Version 5.1
Equation: CIELCh - CIE94 1.00:1.00 Observer: 10° Illuminant: D50
CE-7000A - XA0933 Status: CRIOVV
STANDARD: Red MEASUREMENT TYPE: Reflectance

Standard	*Illum*	*L**	*C**	*h°*				
Red	D50	47.803	59.669	29.734				
Trial	***Illum***	***L****	***C****	***h°***	***DL****	***DC****	***DH****	***DE****
minimum	D50	48.750	59.565	29.513	0.947	-0.028	-0.121	0.955
maximum	D50	47.046	59.278	29.753	-0.757	-0.106	0.010	0.765



APPENDIX 5

A6.1 ProPalette Ink Formulation Manual

1. Getting Started

Refer to the Basics operation manual for information on opening program, calibration, settings, and measuring standards/trials.

2. Opening the database

(The database is normally opened automatically when the program is. The below should only be used if this is not the case. The name envasesdb1.ifs will be displayed at the base of the screen if it is open.)

Before running a formulation the ink database needs to be opened, this can be done as follows:

- Press F10 to display open/create database file screen
- Go to e:\colorant file\envasesdb1.ifs and open.

3. Creating a formulation

In order to create a formulation a target colour must be measured (normally supplied by the customer).

a. Measuring the target colour

- Measure the target colour as a standard (refer to other manual for measuring instructions).

b. Measure substrate

- Press ALT+F3 to display substrate screen.
- Give substrate an appropriate name and click measure.
- On next screen click o.k. until measurement set (3 measurements) is complete.
- Substrate name should now appear in substrate box in top left of main screen.

c. Opening formulation view

- Go to display, then views and click on formulation. This view can also be opened by clicking the button.
- Formulation screen and toolbar will now appear.

d. Setting formulation options

- Click on the button and the formulation options screen will appear.
- Click the components tab.
  - Select all or select own colorants to be used.
- Click resin tab. If the colour required is transparent then select transparent resin for opaque select the opaque resin. Any percentage of resin can be entered depending on requirements.
- Click batch settings tab.
  - Select appropriate thickness (1.5). This should appear in the current thickness box.
- Click save and then close.

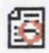
e. Run formulation

- To run formulation click the button.
- Formulations will now be displayed on screen.

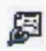
- Select appropriate formulation depending on requirements (normally the formulation with the lowest Delta E).

f. Making a correction

- After a rollout of the formulation has been made at the appropriate thickness and subseqently dried etc… Measure in the sample as a trial.



- Click the button to open the correction view.



- Click the button to open the correction options.
- Select required options. Normally a new batch needs to be made each time rather than adding to the batch. Only allow for new colorants if a theoretical match is still not achieved with a correction. All other options should be left as they, once done click save and o.k.

- Click the button to run a correction. This should now appear along with the original formulation.
- If a second correction is required, save the recipe to the hard drive (same as saving trials and standards). Re-open the recipe and repeat correction process using the 1st correction rollout as the trial.
- This can be continued until a match has been made. A match should 90% of the time be made on the first correction.

APPENDIX 6
FORMULATION EXAMPLE

ENVASES UK LTD
Optiview Quality Control Version 5.1
Observer: 10°
Status: CRIOVV

3/08/04
Equation: CIELCh - CIE94 1.00:1.00
CE-7000A - XA0933
STANDARD: orange
Pigment File: envasesdb1.ifs

10:25
Illuminant: D50

MEASUREMENT TYPE: Reflectance

Id	Colorant Name	Recipe %	Batch Quantity
1	TRANSPARENT TZ-1062	0.0	0.0
3	BLACK 157959	0.6	0.6
11	YELLOW PROCESS 157898	45.2	45.2
12	ORANGE TZ-3800	54.1	54.1
	(100.0 Weight)	100.0	100.0

Cost:	0.0
M1:	0.1
SpD:	0.1
Contrast:	0.0

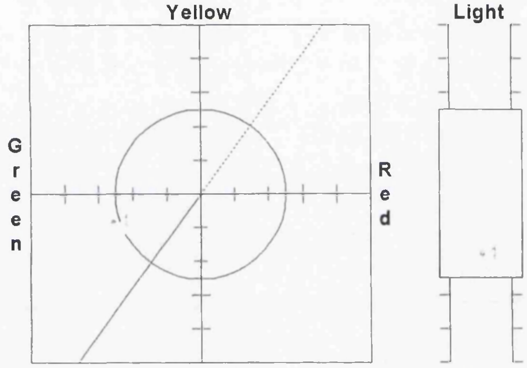
Resin:	TRANSPARENT TZ-1062
Opacity Control:	None
Standard Gloss:	0.0
Colorant File Gloss:	0.0
LCh Weights - L:	1.0
C:	1.0
h:	1.0
Thickness:	1.5
Resin % Min:	0.0
Resin % Max:	100.0
Run full combinatorial:	Enabled
Form. Output Mode:	Weight
Colorants:	All
Hiding Over Light/Over Dark Disabled:	

	DL*	DC*	DH*	DE*
D50:	0.7	-0.1	-0.2	0.7
D65:	0.7	-0.1	-0.1	0.7
TL84:	0.1	0.0	-0.9	0.9

Equation: CIELCh - CIE94 1.00:1.00
Observer: 10°
Illuminant: D50
CE-7000A - XA0933
Status: CRIOVV
STANDARD: orange
MEASUREMENT TYPE: Reflectance

	Standard	*Illum*	*L**	*C**	*h°*				
	orange	D50	59.967	68.781	53.998				
	Trial	*Illum*	*L**	*C**	*h°*	*DL**	*DC**	*DH**	*DE**
1	Trial-003	D50	59.247	67.909	54.540	-0.719	-0.213	0.318	0.815

Illuminant D50



Scale L, a, b: ±2.000
Hue: 54.00° Res: 0.40

References

1. Samuel Pattern, MPhil 2001 - Design and optimisation of aluminium aerosol cans produced by back extrusion.
2. FTA 5th edition 1999 – Flexography: Principles & Practices volume 1.
3. M. J. Prosser, March 1995 – Tinplate Decoration, A review.
4. Andrew Clist, MSc 2000 – The effects of thermodynamic transients on can decoration using waterless offset lithographic printing.
5. J.M.Fetsko and W.C.Walker, American ink maker November 1955 p38 – Measurements of Ink Transfer in Printing Coated Paper.
6. Marianne Klaman, Ingrid Andersson, TAGA 1999 p.418 – Colour shifts in 4-colour printing.
7. Mark Frederick John Bohan, T.C. Claypole and D.T. Gethin "Factors affecting the process stability of heat set web offset press", 1st TAGA/IARIGAI Tech. Conf., Paris, France, September 1995.
8. John MacPhee , TAGA 1988, pp.180-203 – A Definitive strategy for the closed loop control of process colour printing, round 1.
9. John MacPhee and John Lind, TAGA 1991, pp.550-573 – Measurement of ink film thickness printed by the litho process.
10. John MacPhee and John Lind, TAGA 1992, pp.346-364 – More data on the density range of papers and on the measurement of printed ink film thickness.
11. ISO 12647-1:1996 – Graphic technology-Process control for the manufacture of half-tone colour separations, proofs and production prints.
12. Scott Stamm, TAGA 1981, pp.156-173 – An investigation of colour tolerance.
13. Robert Chung and John Compton, TAGA 1991, pp.119-129 – A colorimetric method for visualisation and determining colour tolerances of printed colours.
14. G. Wyszecki and W.S. Stiles, Color science, 1982
15. Roderick Mc Donald 2nd edition 1997, Colour Physics for Industry, Chapter 1.
16. Roderick Mc Donald 2nd edition 1997, Colour Physics for Industry, Chapter 6.
17. R. W. G. Hunt, 3rd edition 1991 – Measuring Colour.
18. X-rite, 2002 - A guide to understanding colour communication, p.18.
19. T. Johnson, Phil Green, "Issues of Colour Measurement and Assessment", TAGA 1999, p.522.
20. Roderick Mc Donald 2nd edition 1997, Colour Physics for Industry, Chapter 4.
21. www.pantone.com
22. www.signplusbanners.com/vinyls/pantone_book.html
23. GretagMacbeth – Calibration Data Preparation Guide for ProPallete.
24. John MacPhee and John Lind, TAGA 2002 p.479 - Insight into the relation between print density and ink film thickness.
25. Veeco Process Metrology, June 1998 – WYKO Surface Profilers technical reference manual.
26. N. Logothetis 1992, Managing for total quality, p.194.
27. www.raytek.com. (Model ST20).
28. www.fischer-technology.com/products/iso.html
29. Mall and Herlan – Print Press Instruction manual.
30. Eduardo Alegria, DIC Coatings 'Private communication'.